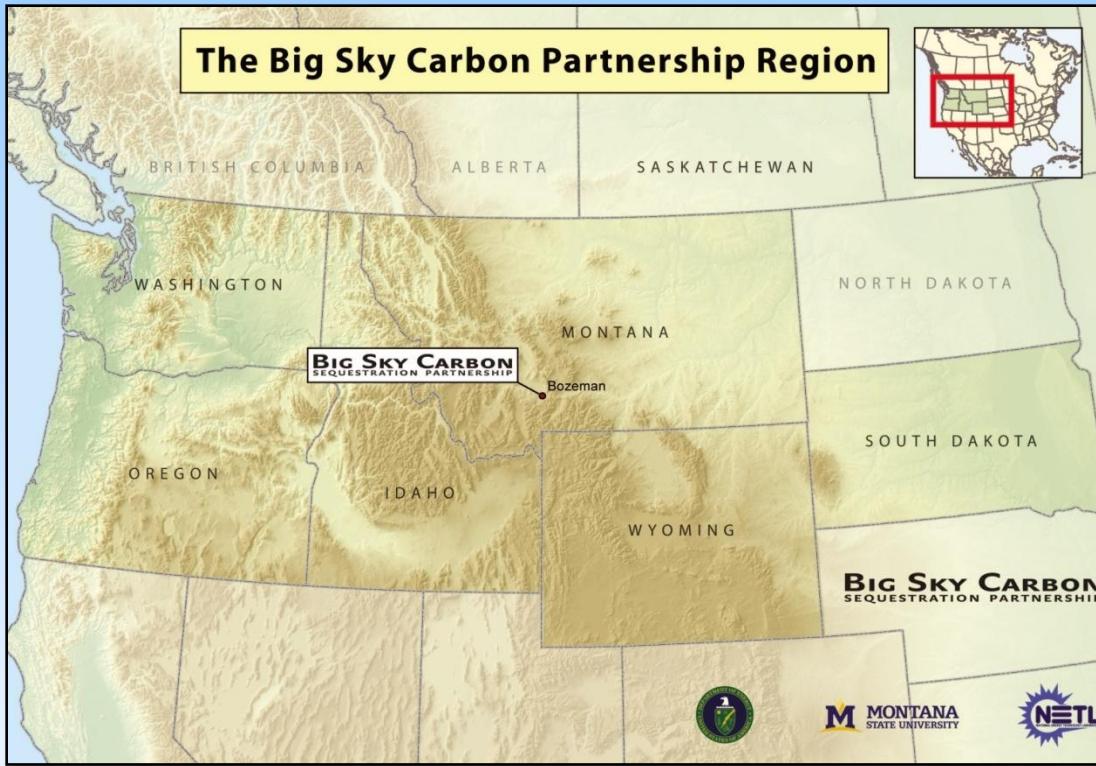


Big Sky Carbon Sequestration Partnership

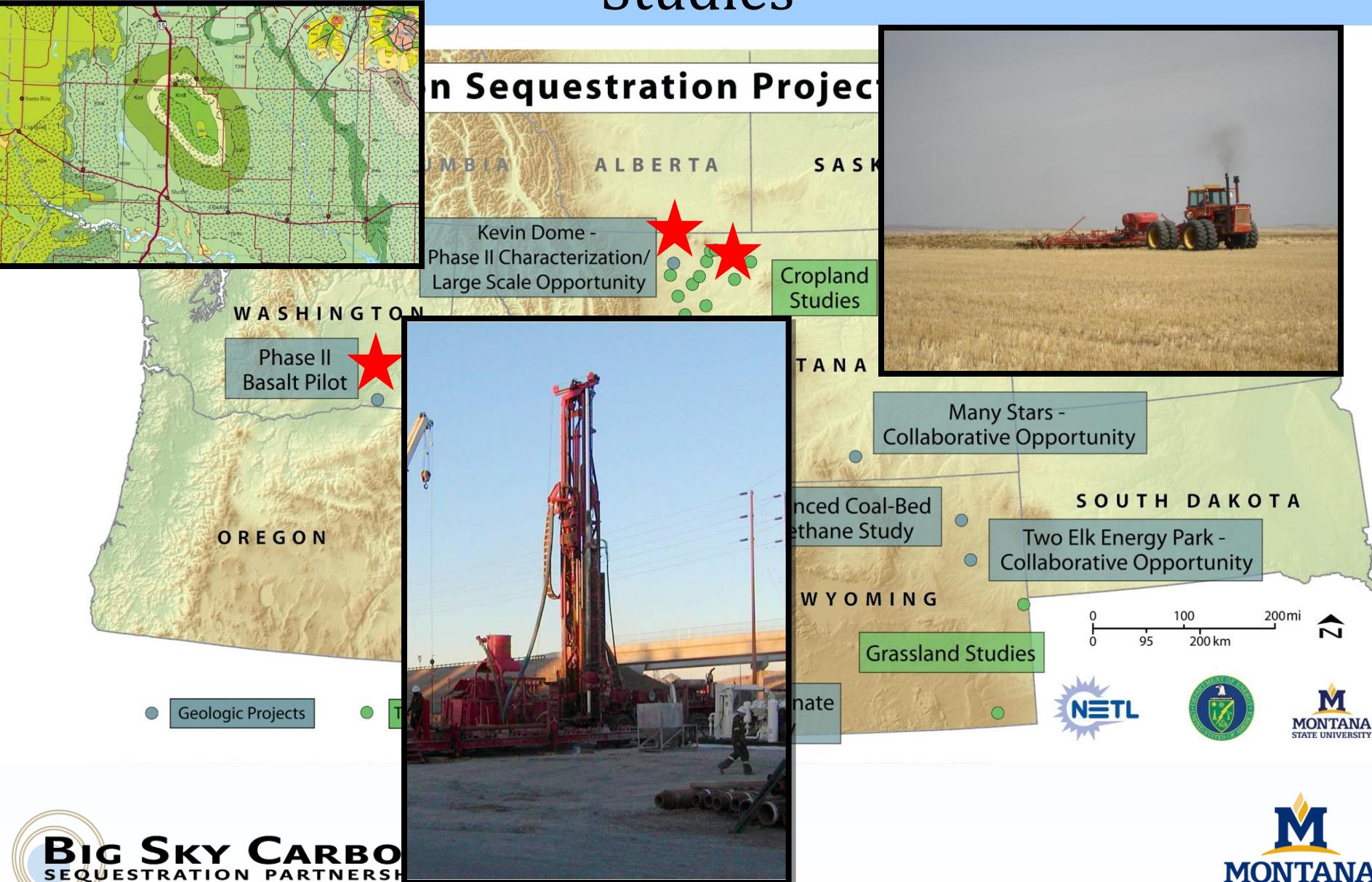


RCSP Meeting
October, 2010
Pittsburgh, PA

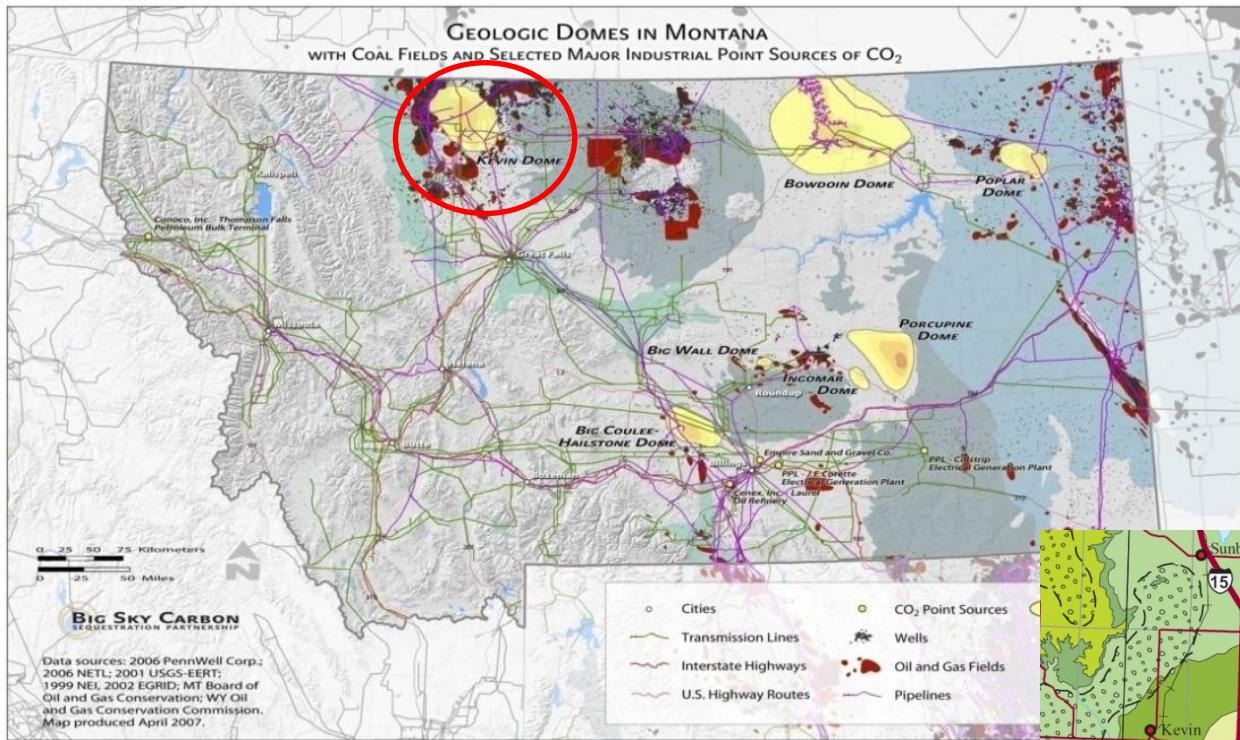
Large Scale Test - Pragmatic Issues

- Reasonably large quantity source of CO₂
- A good quality storage reservoir
- Good quality seal
- All in close proximity

Phase II Pilot Scale Tests and Characterization Studies

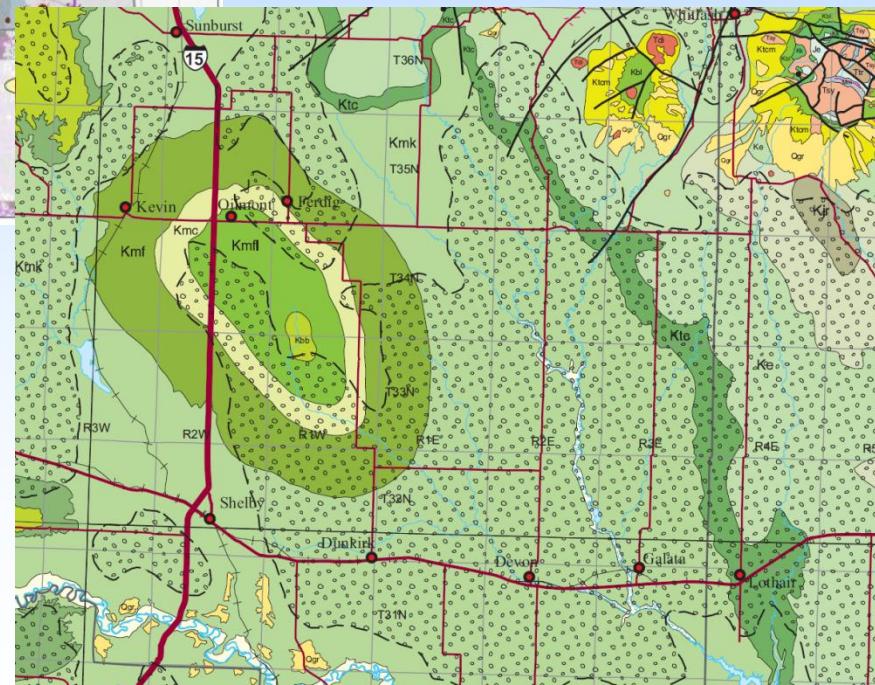


Kevin Dome Project



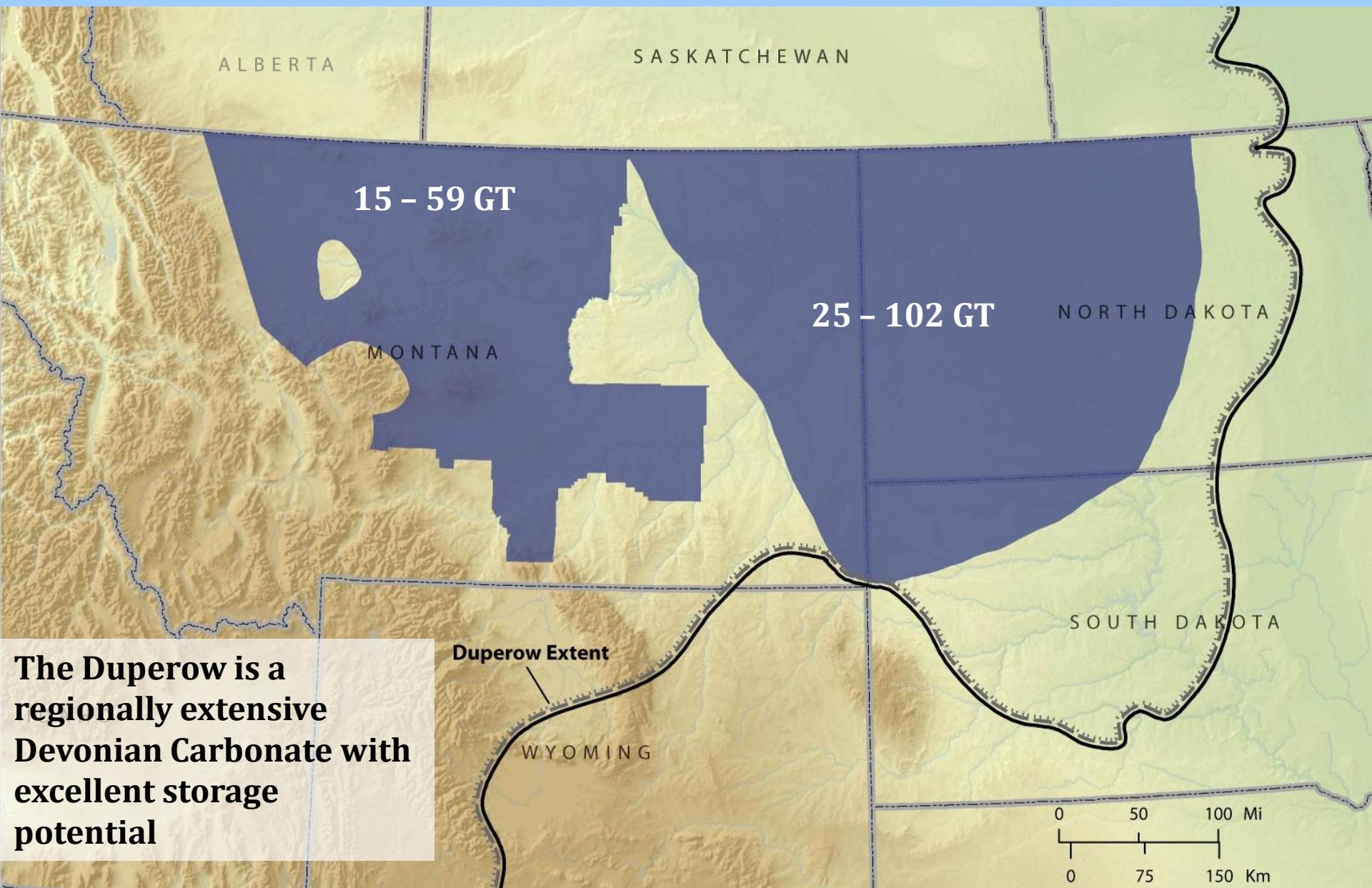
Surface Geology – Kevin Dome

- Naturally occurring CO₂ reservoir.
- Possible “buffer” storage for EOR.
- Possible location for additional storage.



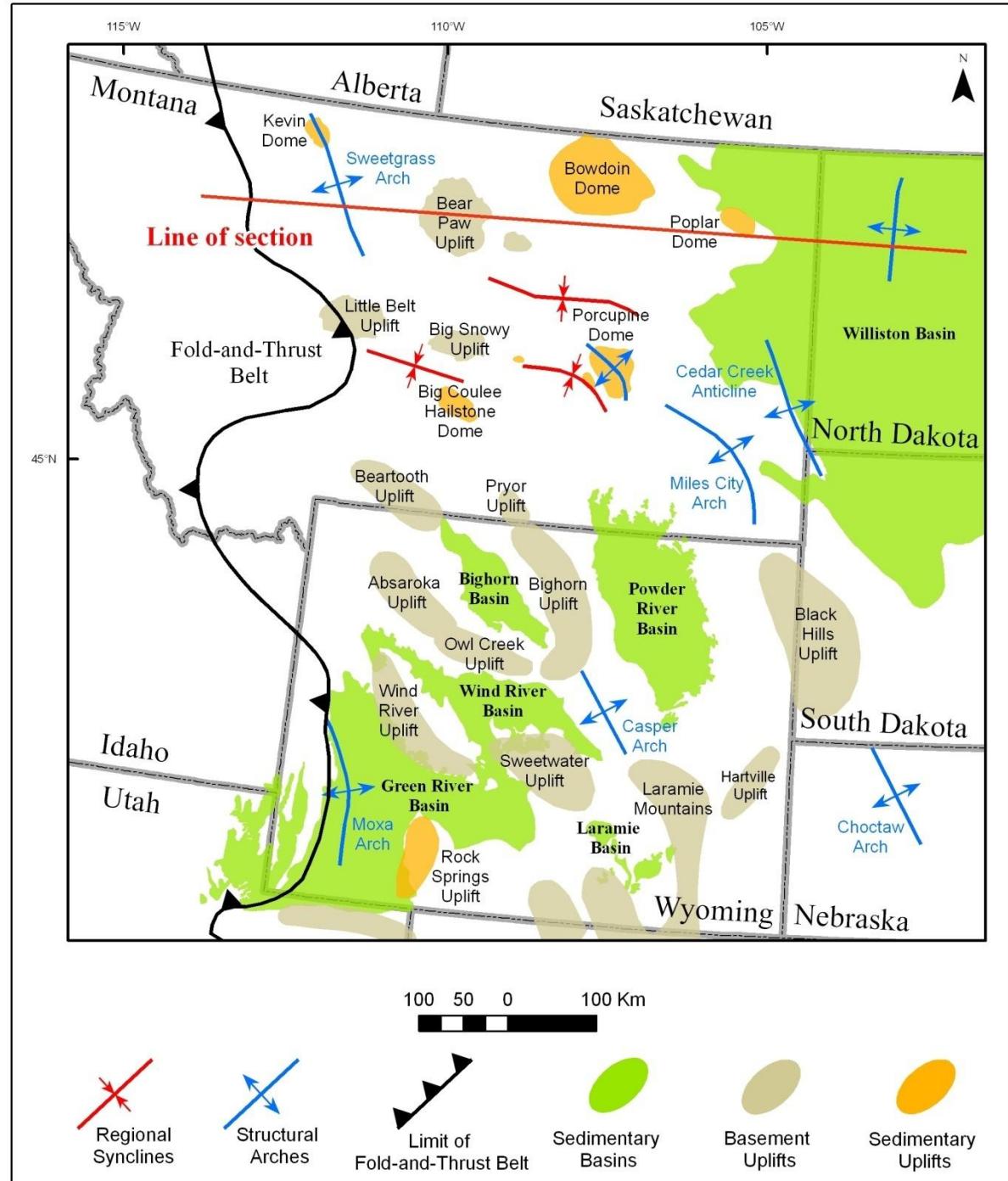
(modified from MBMG, 2007)

Duperow Extent / Resource Estimate

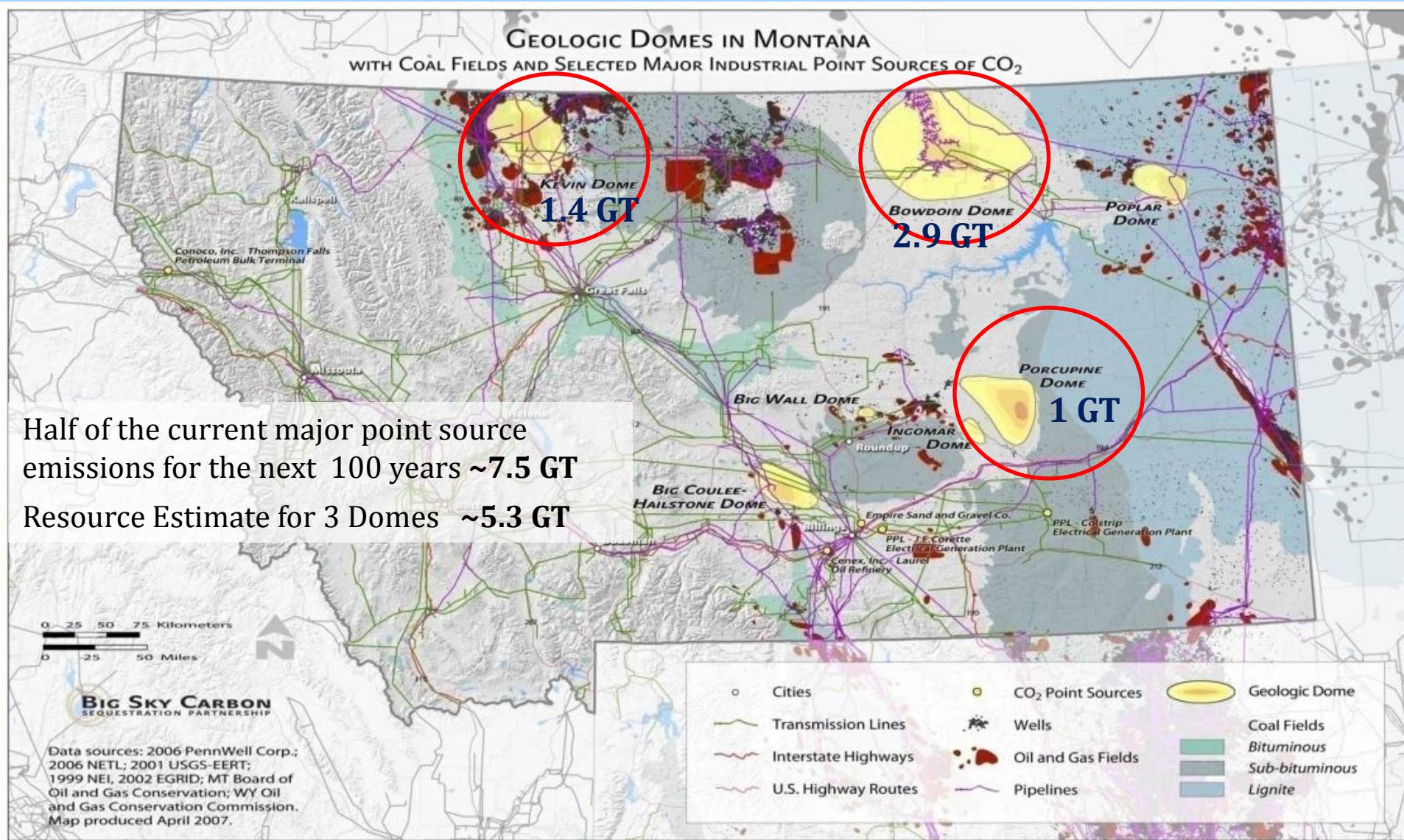


Large structural closures, and in particular, domes, represent an attractive early sequestration target in the Big Sky region.

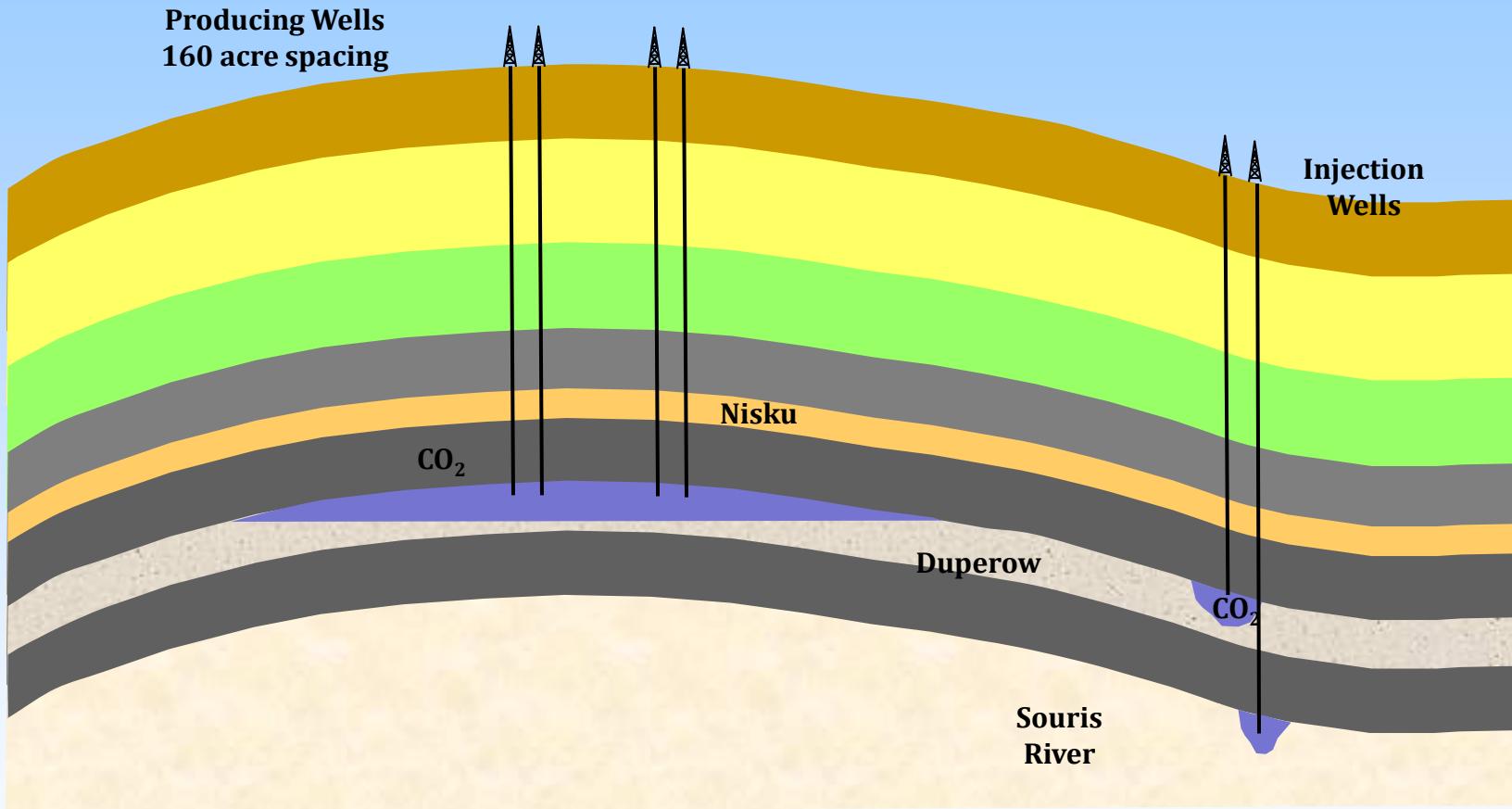
These domes provide the additional security of structural trapping and, in some cases, have already shown the ability to trap CO₂ over geologic timescales.



Resource Estimate for Three Montana Domes



Kevin Dome Large Scale Injection Schematic



Kevin Dome Project

Project Goal:

Generate detailed data and maximize learnings by making use of special properties of the project

- coupled natural analog study
- strong geophysical partner

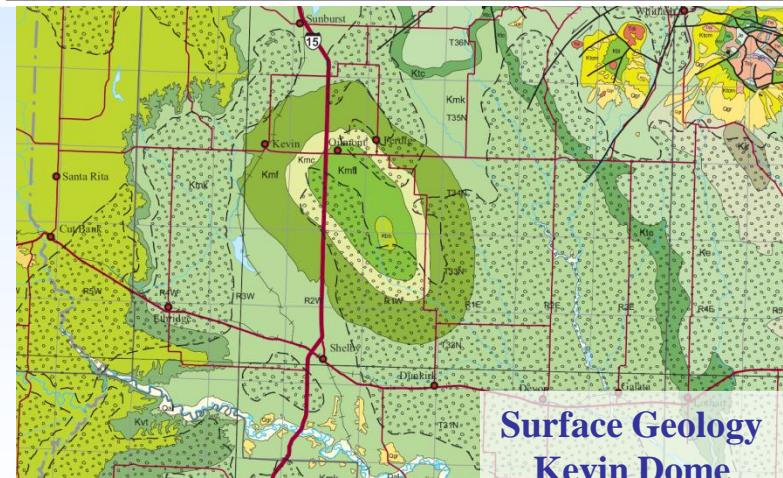
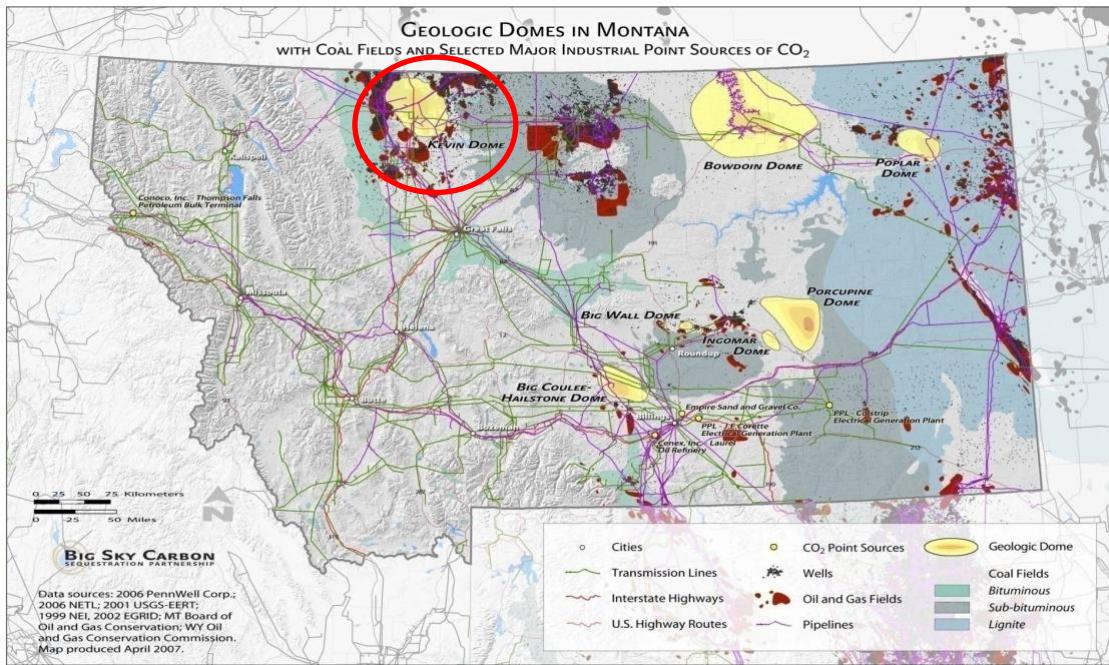
Project Status:

Project planning is complete

Project costs are being determined (~95% complete)

An application is being prepared for submission to DOE

Kevin Dome Large Scale Project



A Kevin Dome Project Would Allow Study Of:

- Storage in the regionally significant Duperow.
- Storage in regionally significant domes.
- Comparison of a natural analog to new storage including geochemical changes.
- Potential for stacked storage
- Potential for detection limit tests
- Impact of additional storage at flanks of domes

(modified from
MBMG, 2007)

Performing Partners

- Montana State University
- Vecta Oil and Gas
- Altamont Energy
- Schlumberger
- Lawrence Berkeley National Lab
- Los Alamos National Lab
- Idaho National Lab
- Lawrence Livermore National Lab
- Columbia University
- Washington State University
- Oregon State University

Large Scale Test

Requirements for Storage

Regulatory
Compliance

Capacity

Formation thickness
Areal extent
Porosity
Compartment size
Water Quality

Injectivity

Permeability
Compartment size
Geochemistry
Mechanical properties

Storage Security

Seal impermeability
Seal continuity
Seal thickness
Geochemistry
Mechanical Properties

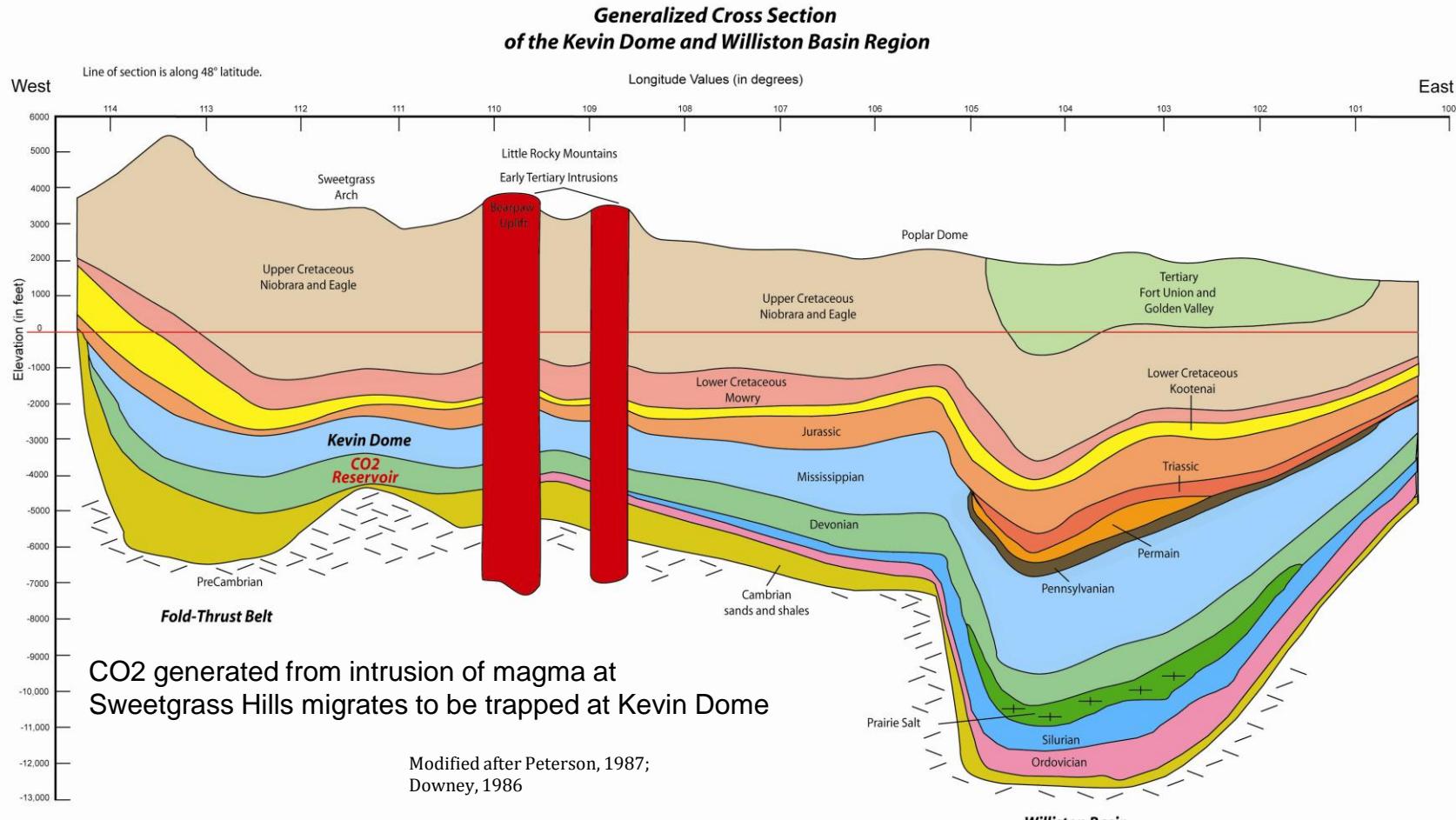
Geology of Kevin Dome

- Structure of dome is very large: over 750 square miles of closure
- CO₂ is naturally trapped in the Devonian Duperow (dolomite) Formation proving *seal integrity, compatibility* of formation with CO₂, and *trap integrity* over geologic time
- Structure is not full to the spill-point with CO₂ at the Duperow level
- A brine aquifer extends beyond the limits of the dome → greater potential for sequestration
- The Nisku (predominantly limestone) contains some small zones of porosity and permeability
- The Souris River formation may have sequestration potential, but there is very little well control to confirm
- The Potlach Anhydrite caps the Nisku, tight carbonates with interbedded evaporites cap the Duperow and separate the upper and lower Duperow

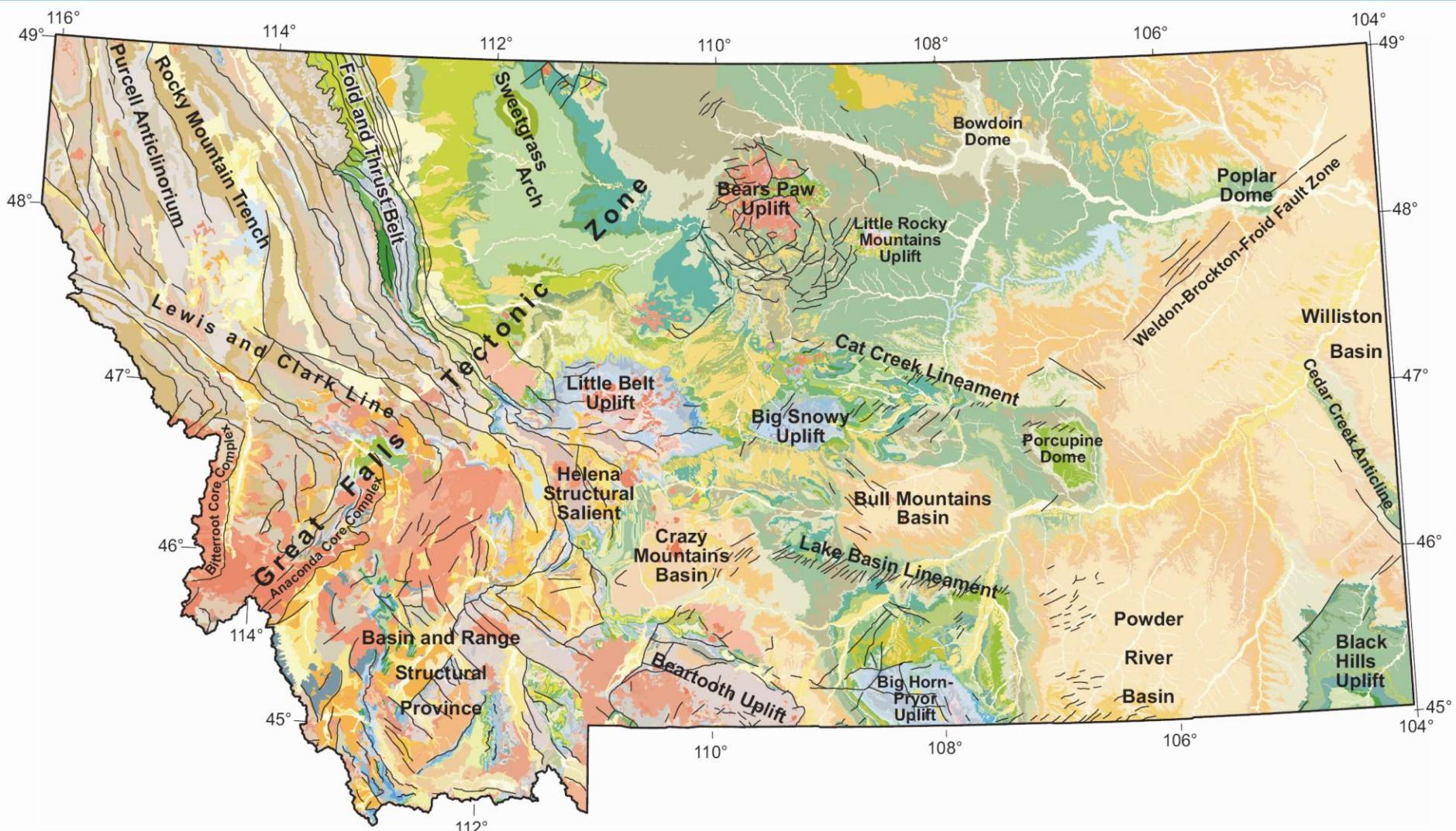
CO_2 Volumes in Duperow Formation at Kevin Dome – Equivalent to Commercial Scale Site

- CO_2 in place and sequestration capacity per square mile
 - Upper Duperow = 1,084,323 Tons (19 BCF CO_2)
 - Lower Duperow = 1,198,694 Tons (21 BCF CO_2)
 - Total Duperow = 2,283,017 Tons (40 BCF CO_2)
- 324 sq.miles with Upper Duperow CO_2 X 19 BCF/ sq. mile = 6.156 TCF CO_2 in place
- 216 sq. miles with Lower Duperow CO_2 X 19 BCF/sq. mile = 4.104 TCF CO_2 in place
- **Potentially 10+ TCF CO_2 in place (~600MM tons)**

Schematic East-West Cross Section

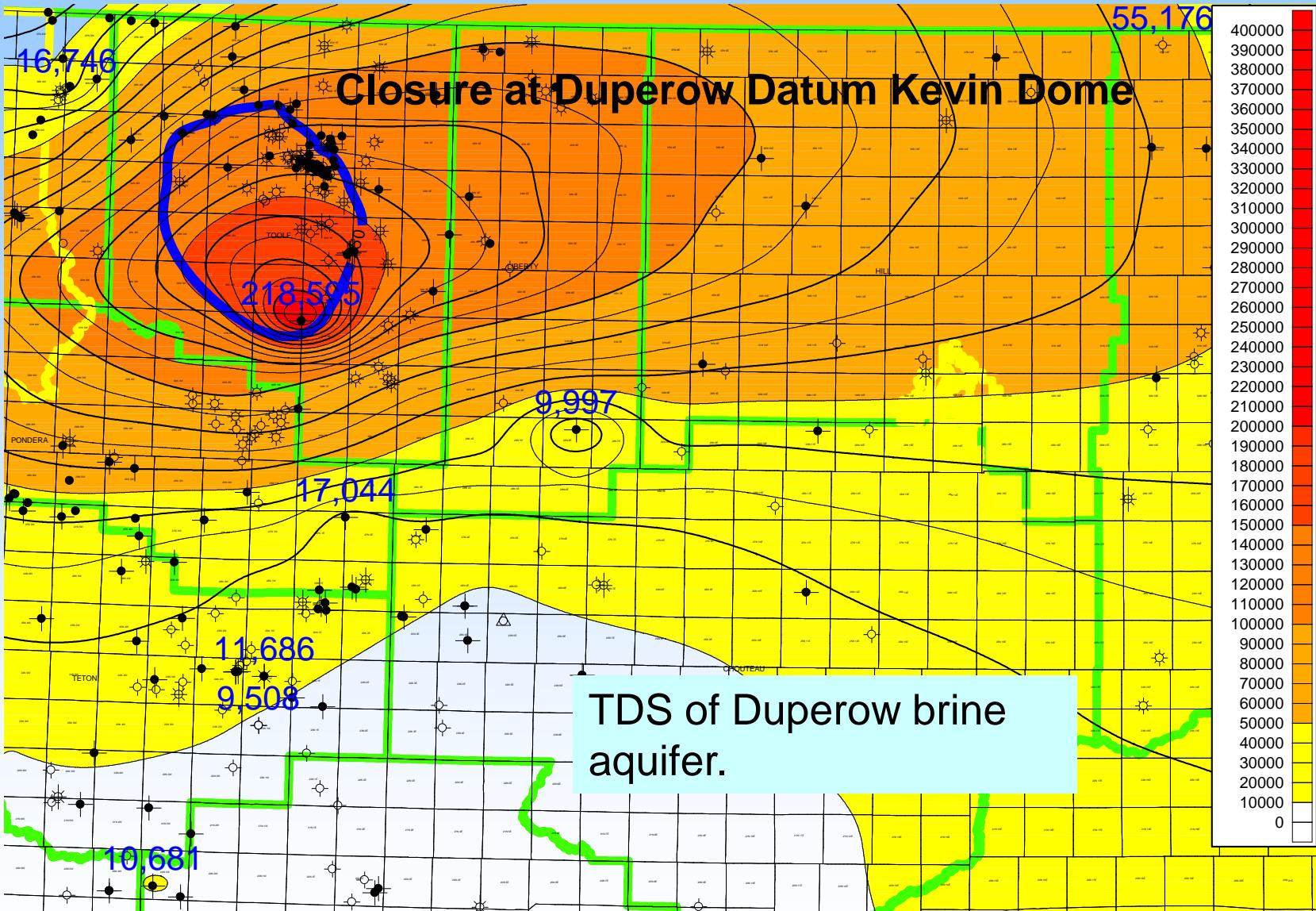


Site Suitability

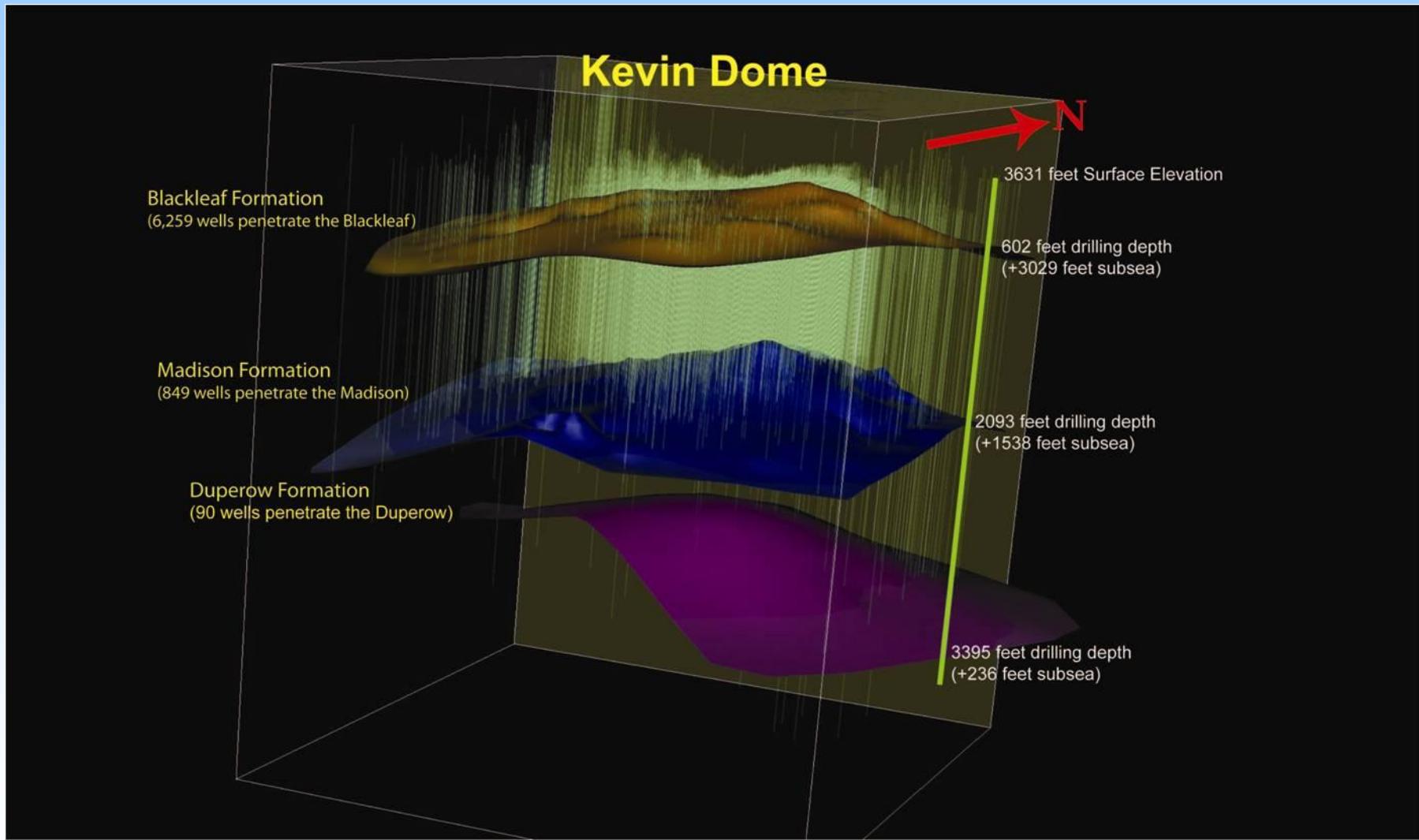


MAJOR TECTONIC FEATURES

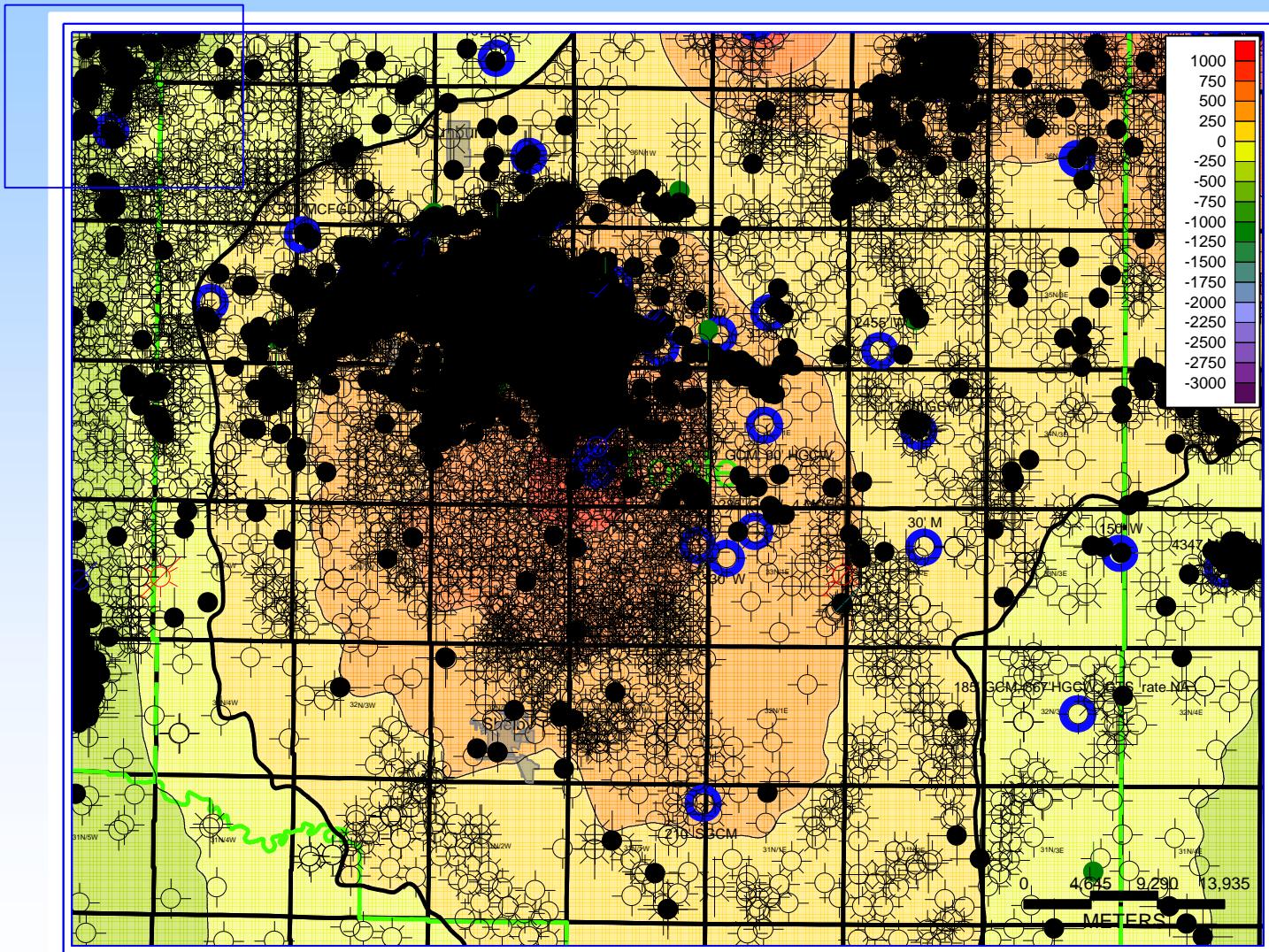
Site Specific Water Quality



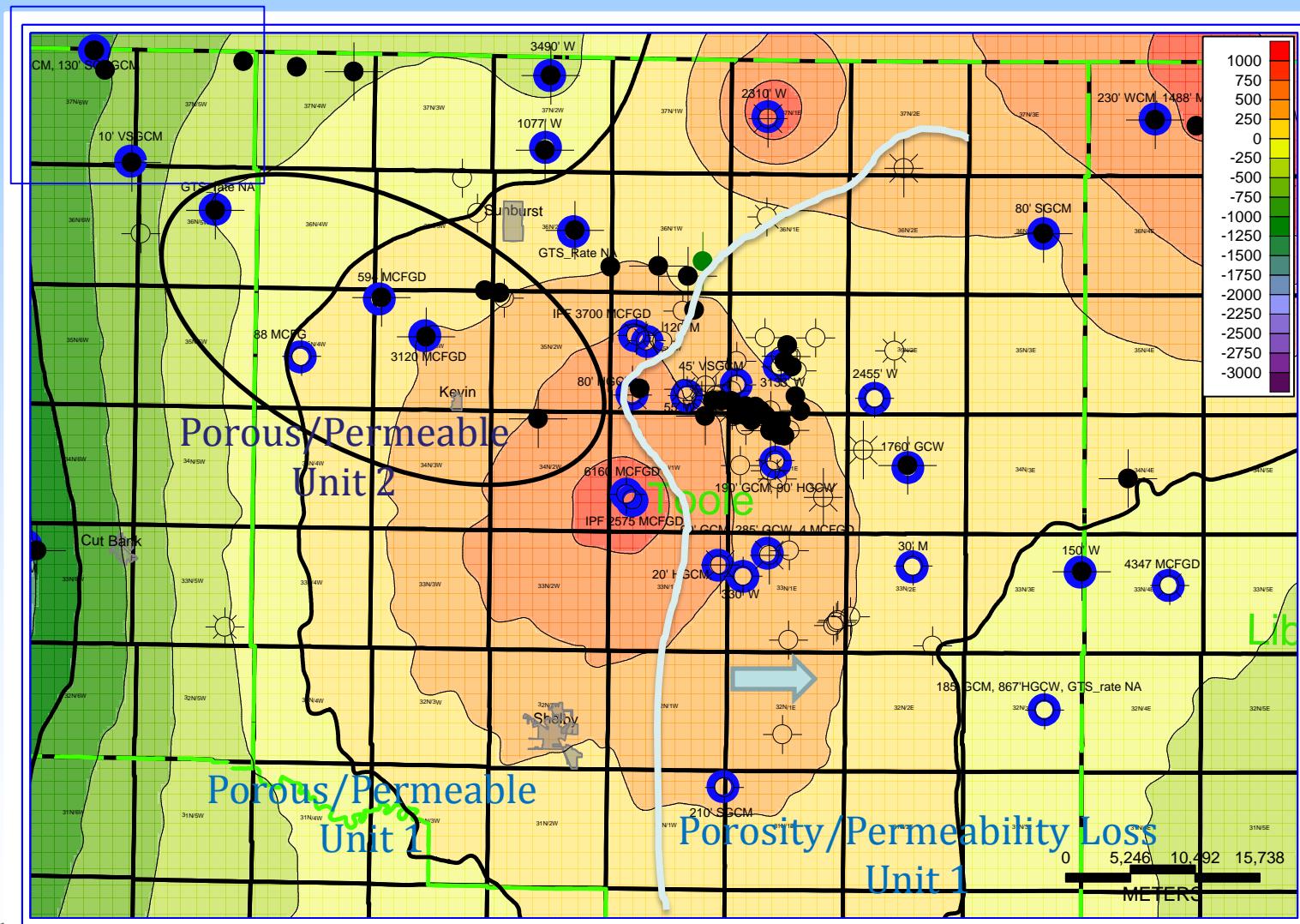
Kevin Structure Tops & Well Penetrations



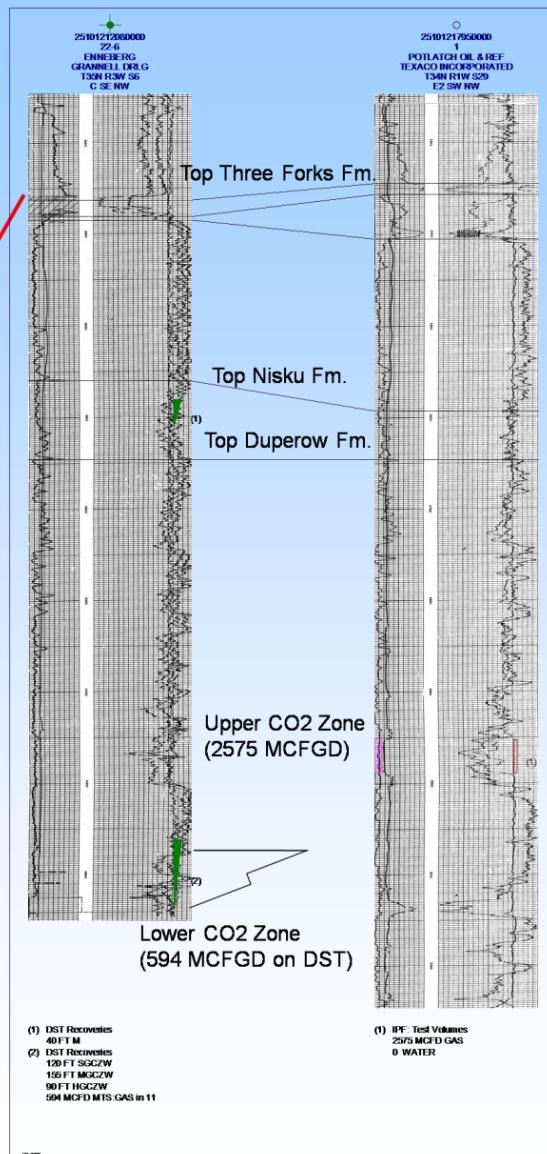
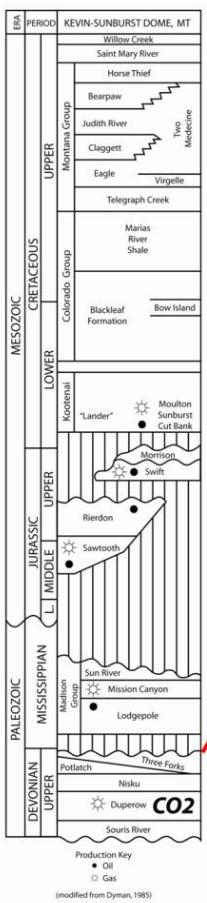
Kevin Dome – All Wells



Kevin Dome – Duperow Penetrations



Stratigraphy



Nisku Limestone ~ 50 – 75 ft total thickness with a 10 – 25 ft thick porosity zone

Bakken Sh.
(Regional Seal)

Potlatch Anhydrite
(Regional Seal)

Potlatch Top

~ 175'
Anhydrite

Nisku Top

Duperow Top

Caprock
Upper Duperow
Anhydrites

Upper Duperow
~200' tight
carbonates and
anhydrites
caprock

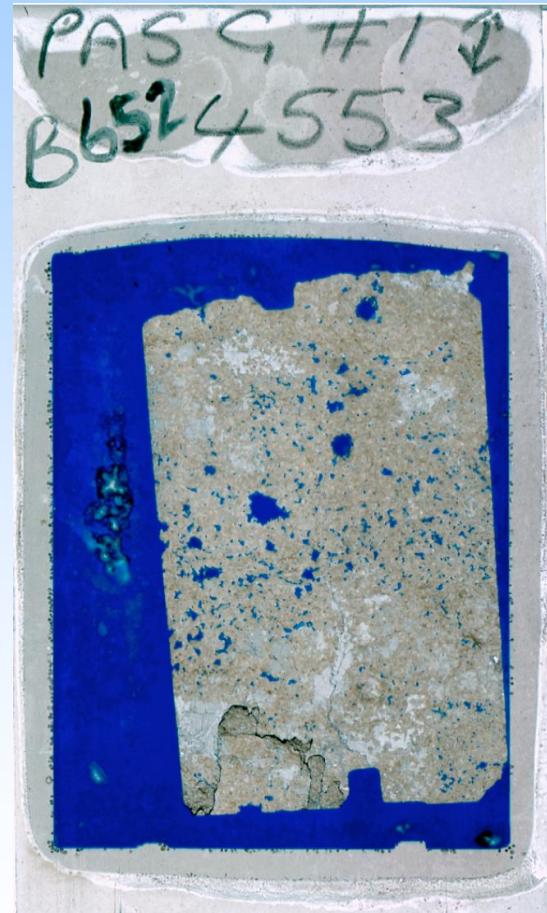
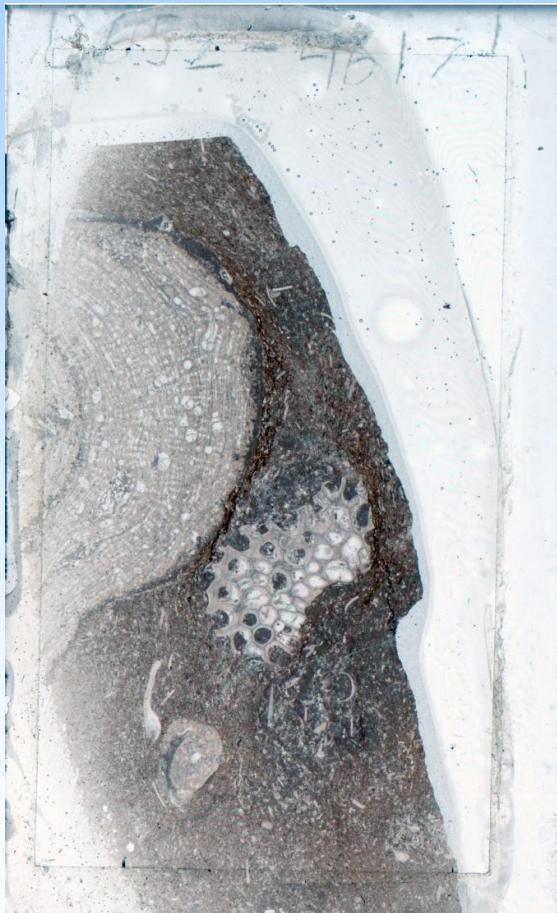
~ 100' Duperow
Porosity (CO₂)

100 feet

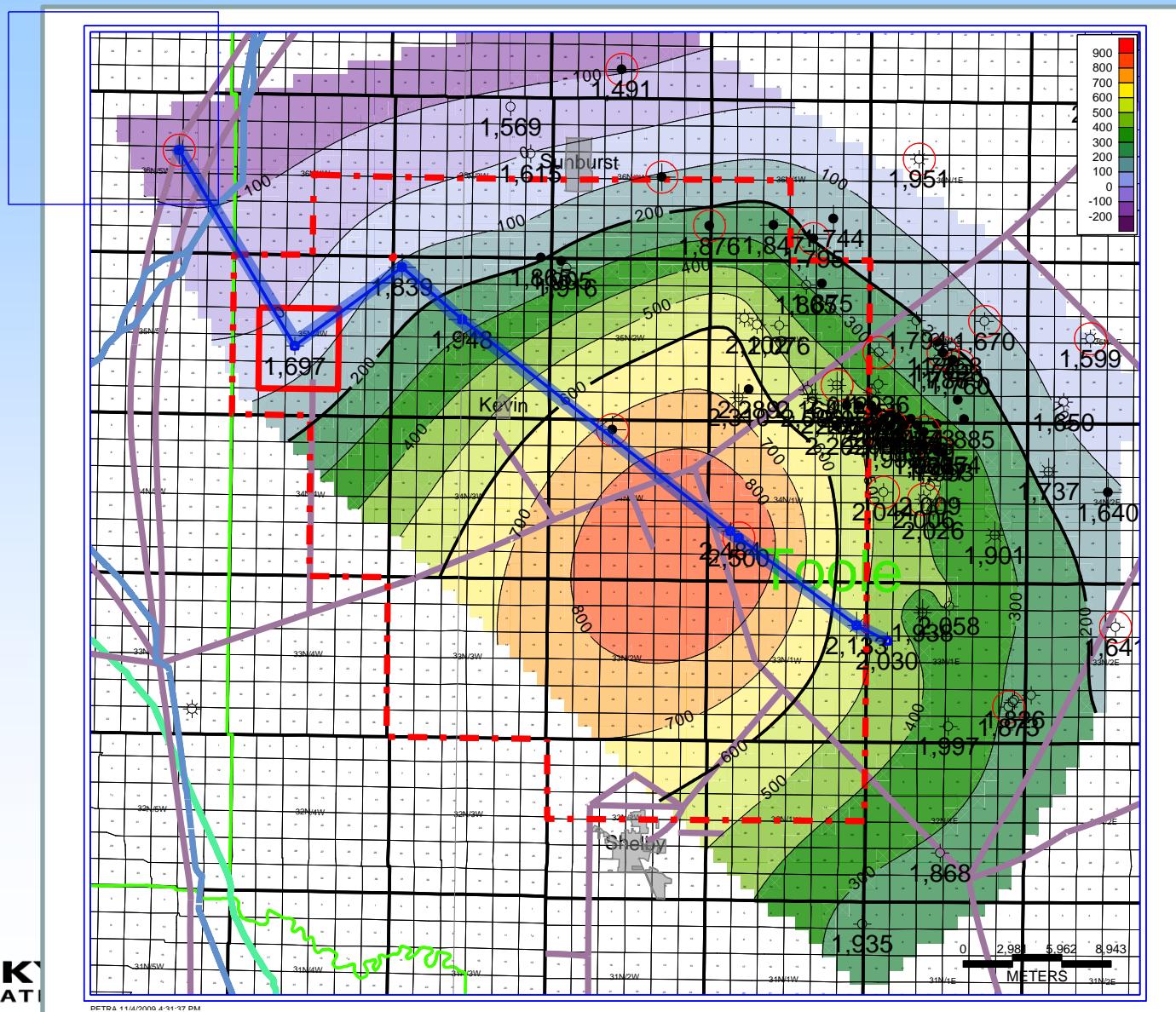
Souris River Top

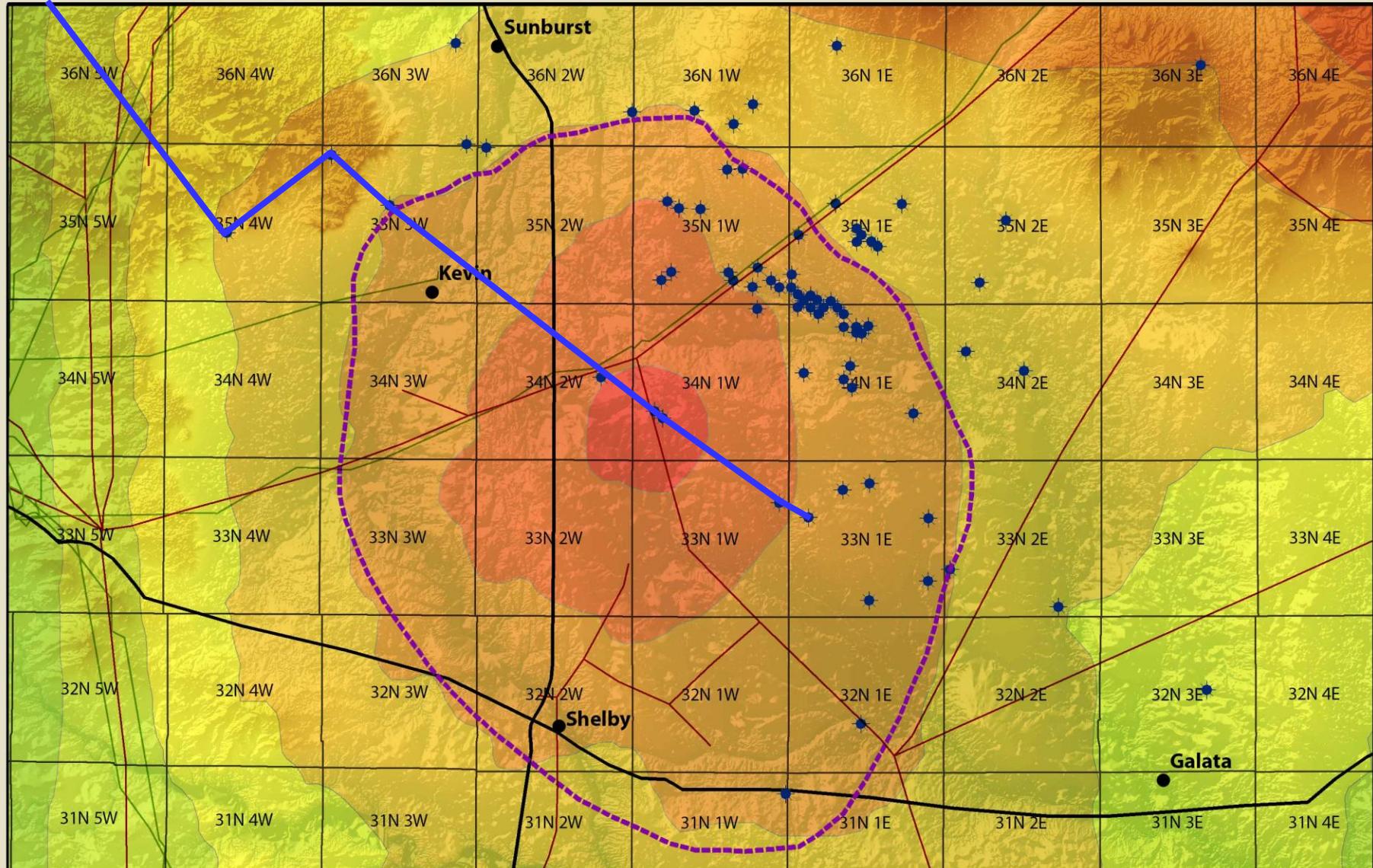


Representative Duperow Thin Sections:



Structure Top Duperow, Area of Interest Outlines, Pipelines, Line of XS



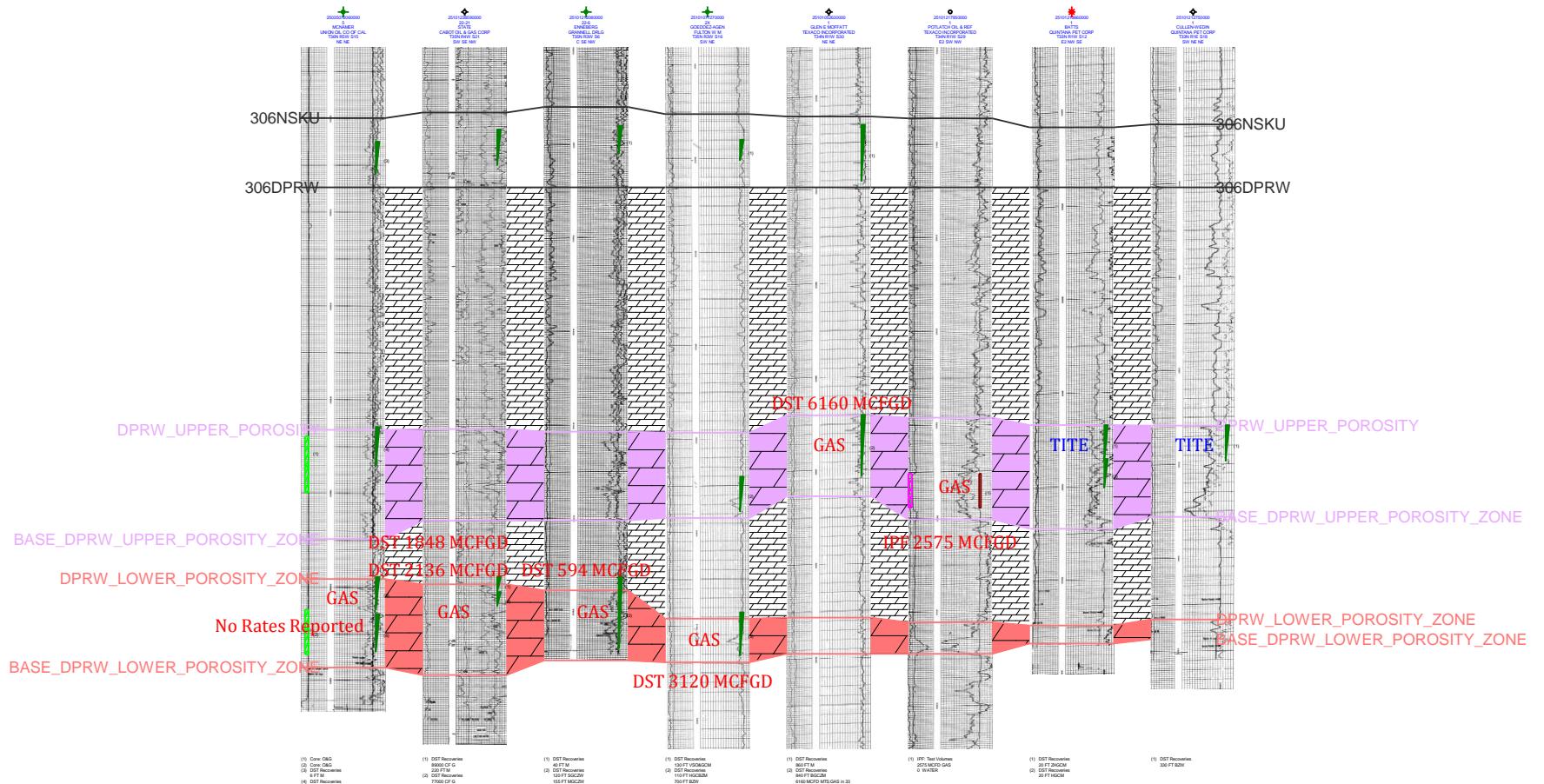


CONFIDENTIAL - internal BSCSP use only

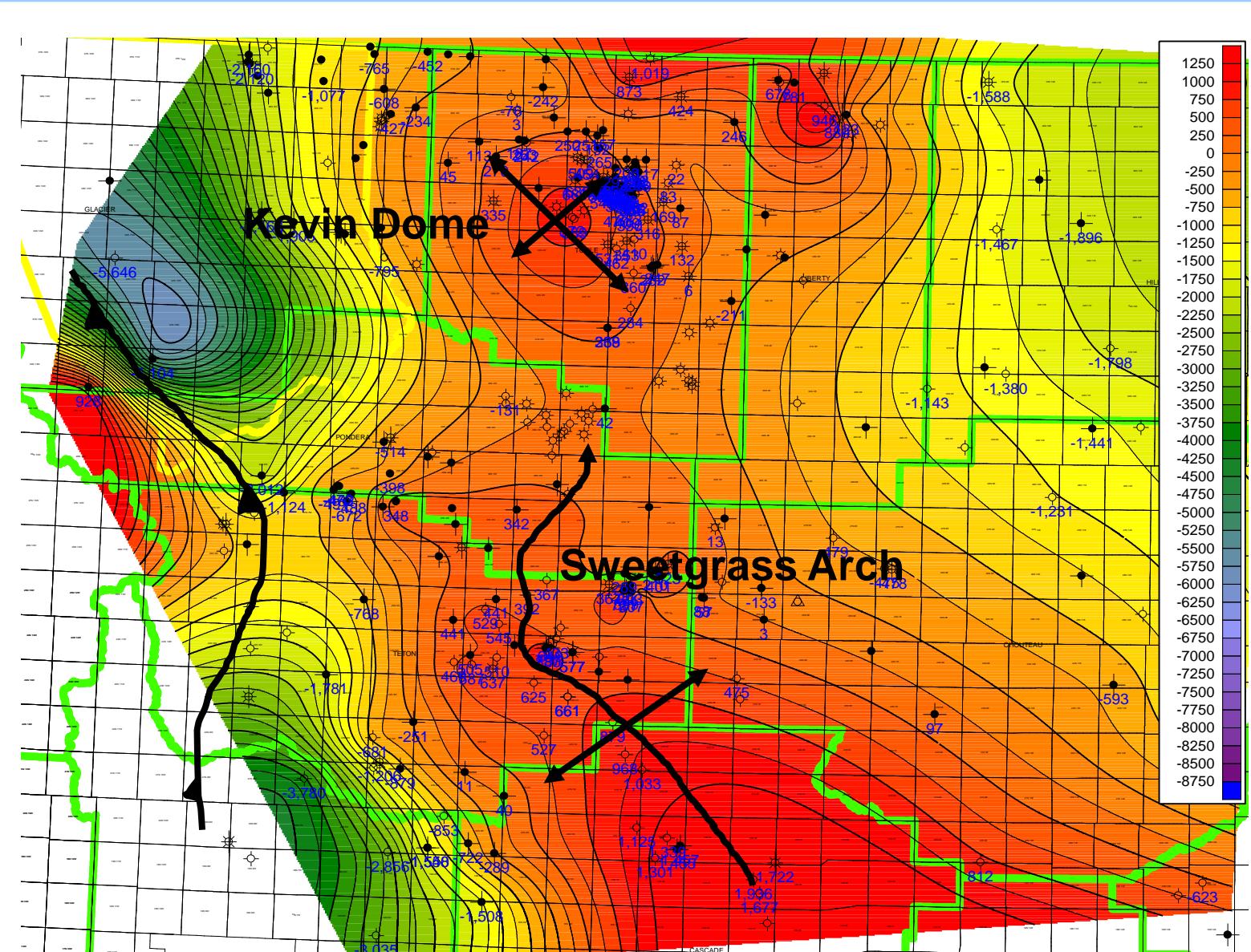
0 2 4 8 Km



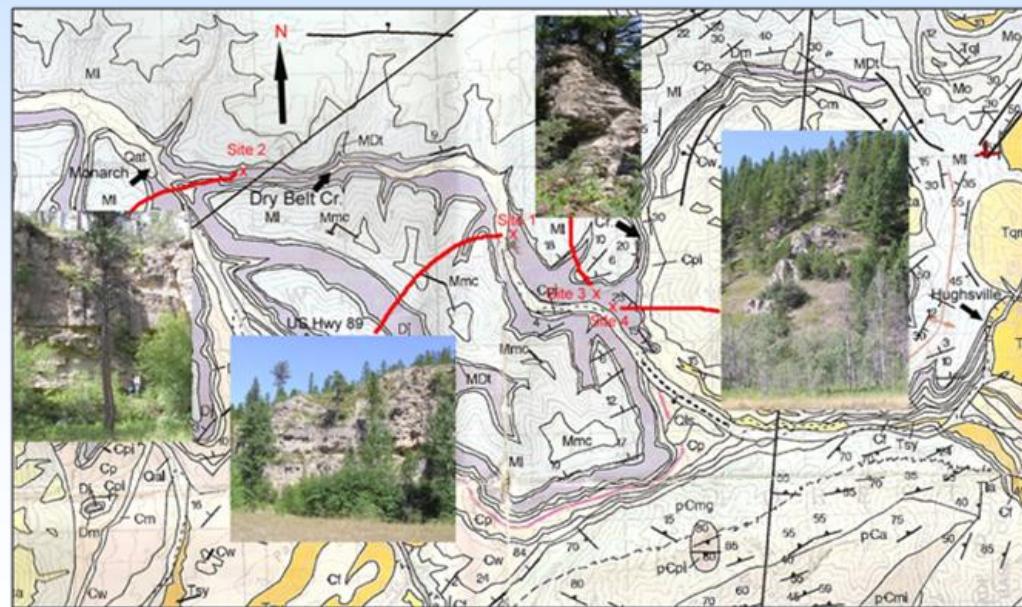
NW - SE Cross Section Kevin Dome



Structure Top Duperow – Duperow Penetrations Shown



Outcrop belt of the Devonian Duperow Fm. Near Monarch, Montana and locations of measured sections.

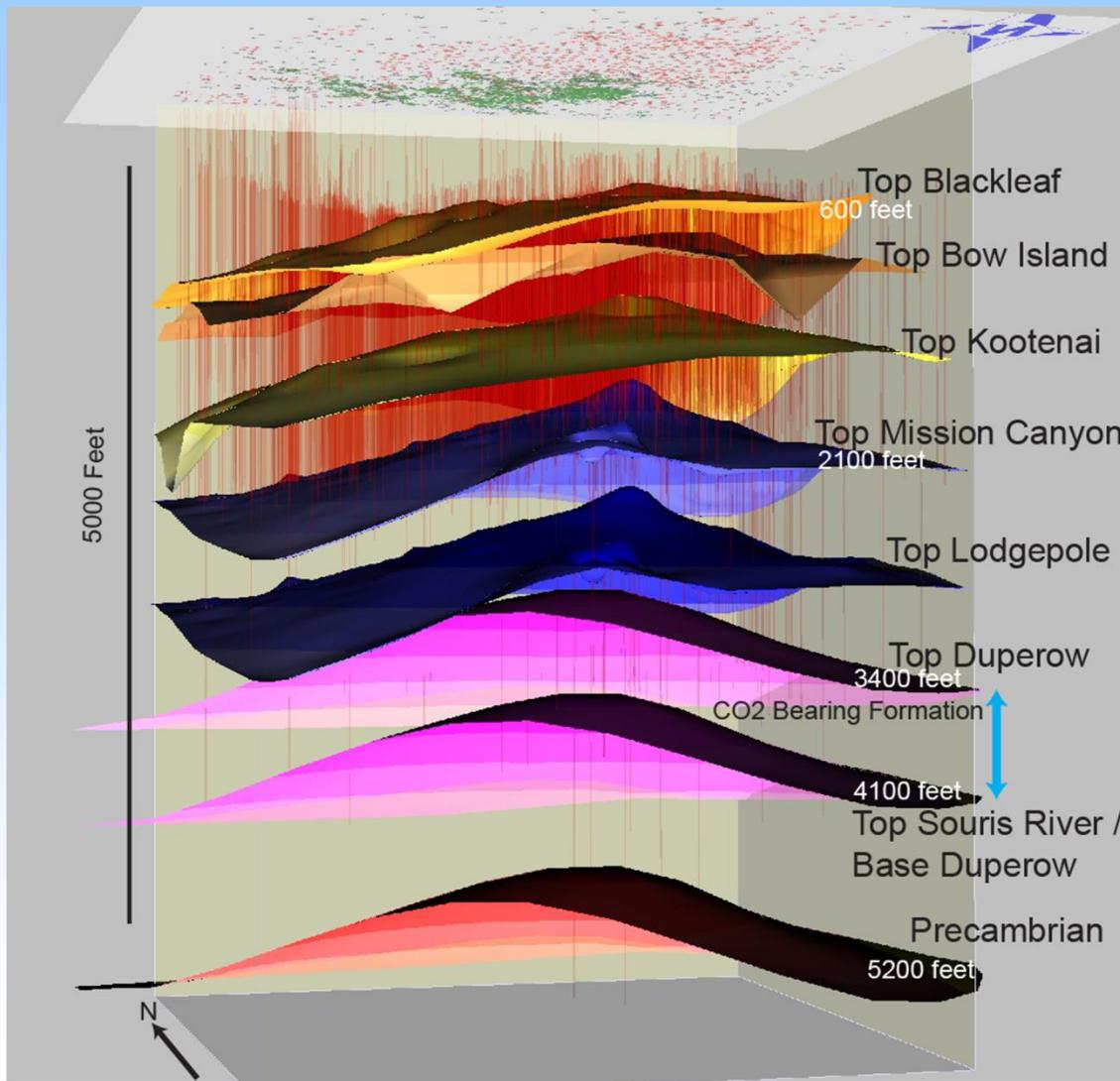


Duperow Fm. Montana Disturbed Belt



3d Reservoir Model

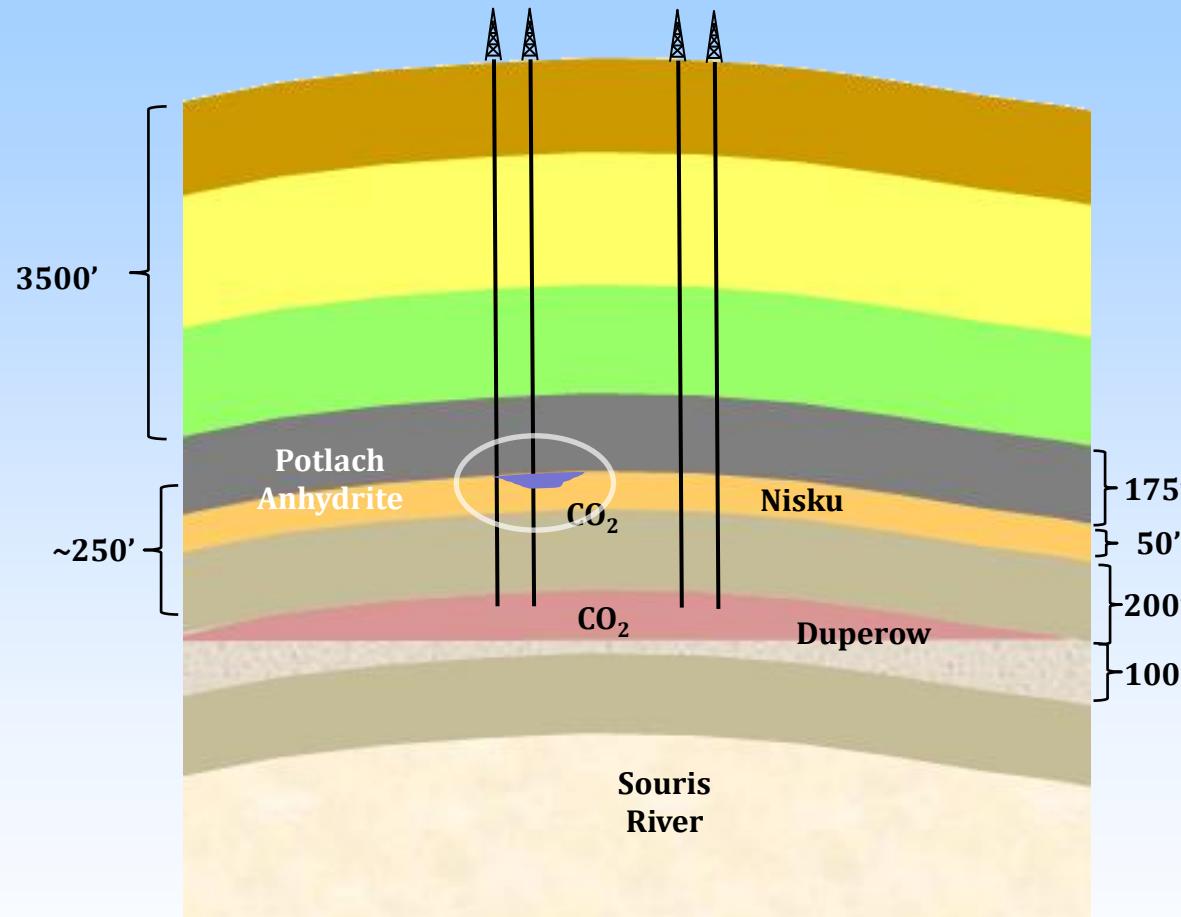
Kevin Dome



Project Parameters

- Initial injection is proposed into the saline aquifer of the Devonian Duperow formation down-dip from naturally occurring CO₂ on Kevin Dome.
- The Souris River formation will also be investigated for potential stacked storage
- A small injection into the Nisku above the CO₂ reservoir will allow tests of detection limits for stacked storage
- The Potlach anhydrite (~150 ft thick) provides a highly competent seal above all injection targets

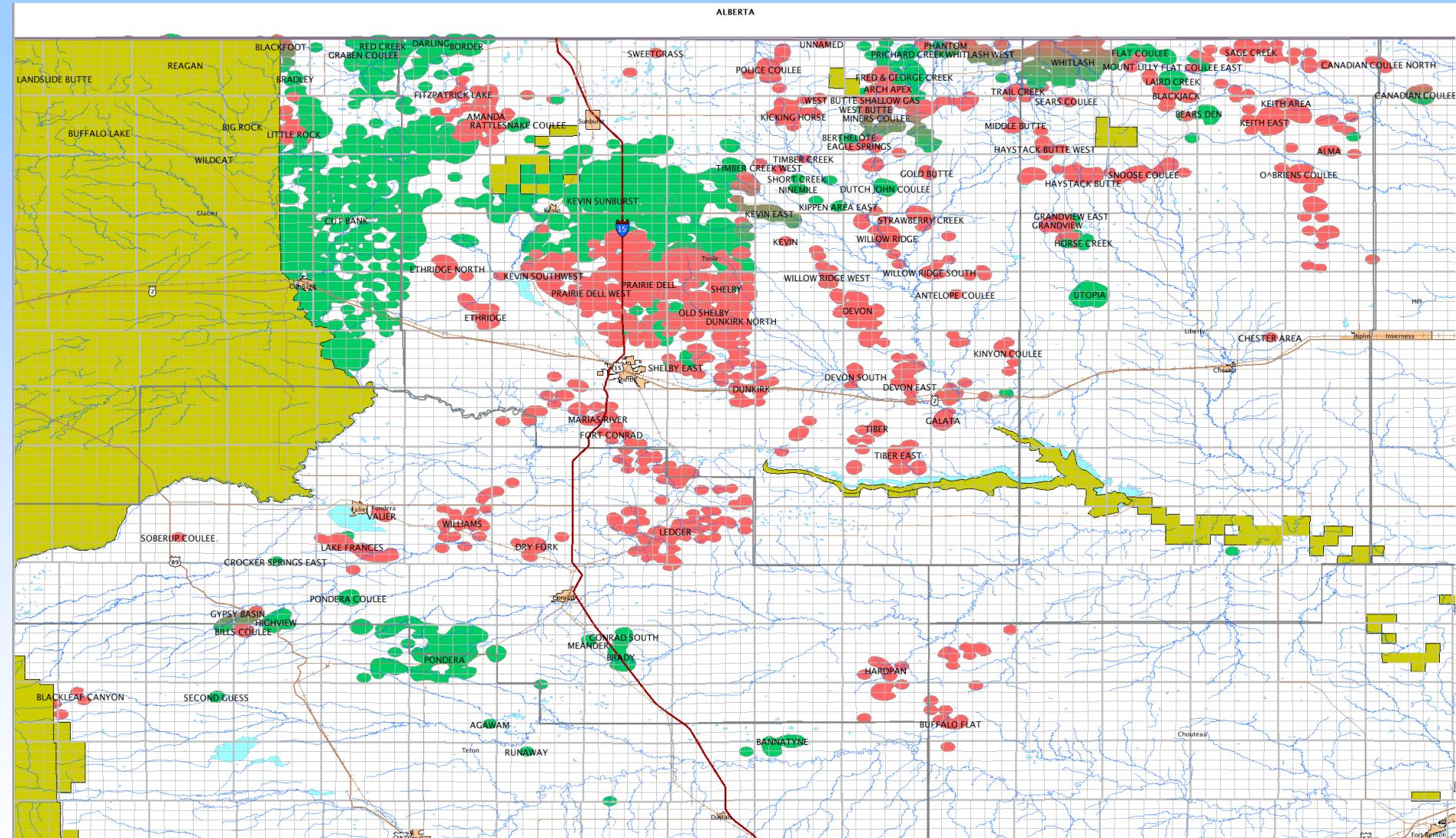
Kevin Dome Stacked Storage Detection Schematic



Outreach

- **Development of Outreach Materials**
- **Public Outreach Surveys**
- **Community Engagement**
- **Legislative Workshops**
- **Multimedia**
 - Involve MSU MFA in Science Filmmaking
 - Products will include multi-platform, 360-degree media documentation, including short films, podcasts, comprehensive, easily accessible web content, and interactive options
- **Collaborative Opportunities and Information Exchange**

Oil & Gas Fields



Population Centers



Sunburst



Kevin



Shelby

Lethbridge 75 Mi N of
Sunburst

Great Falls 85 Mi S of
Shelby



Permitting

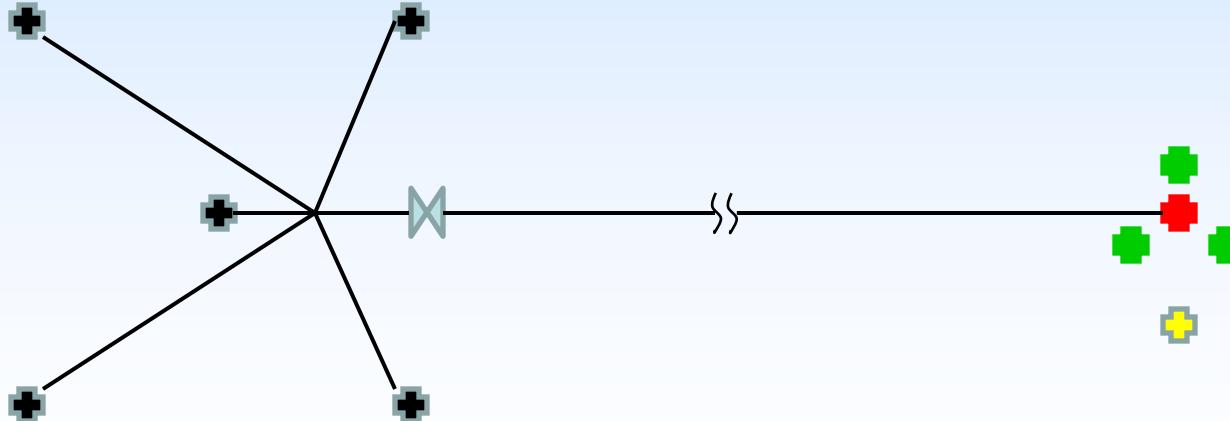
Permitting Activity	Responsible Agency	Time Requirements (in days)
Drilling		
File Application for Permit to Drill (APD)	Montana Board of Oil and Gas (MBOG), Montana Department of Natural Resource Conservation (DNRC), Montana Department of Environmental Quality (DEQ) and the Environmental Protection Agency (EPA)	120
Drilling Plan	MBOG, DNRC, DEQ, EPA	180
Surface Use Plan of Operations (SUPO)	MBOG, DNRC	180
Pipeline Permitting		
	MBOG, DEQ, Office of Pipeline Safety (OPS), DNRC, ROWs to be obtained from individual landowners	180
On Site Visit		30
Cultural Survey	State Historic Preservation Office (SHPO)	120-240
Threatened and Endangered Species Survey	United States Fish and Wildlife Service (USFWS) or Montana Department of Fish, Wildlife and Parks (FWP)	120 -240
UIC Application		
Class V Injection Well	DEQ, EPA, MBOG	120-180
Monitoring Wells	MBOG	120
Water Rights	DEQ	5 days – investigation only as the need for a water right is not expected
Temporary Use Permit	DNRC	60
NEPA and MEPA – Categorical Exclusion (CX) or Environmental Assessment (EA)	DEQ, EPA, MBOG, DNRC	365
Record of Decision (ROD)	EPA, MBOG, DEQ, DNRC	180-365
Stipulations	DNRC, FWP, MBOG, SHPO, Surface Owner	90

Modeling

- Multiphase Flow and Reactive Transport Modeling
- Modeling of Caprock Sealing Performance
- Geomechanical Modeling of Fault-Failure Envelopes
- Simulation of Induced Seismicity and Microseismicity
- Geochemical Modeling

Wells / Infrastructure

- Producing Wells
 - 5-spot, 160 acre spacing
- Single Injection Well
- Four Monitoring Wells
- Gathering System
- 1-2 stages of compression



Cores

- Cores to be cut in 1 producing well, the injector and 1 monitoring well
- Formations & Thicknesses
 - Potlach Anhydrite 60'
 - Nisku 60'
 - Duperow 120' (porosity zone and cap zone)
 - Souris River 60'
- Side Wall Cores from injector & 1 monitoring well after injection stops
- Core Testing & Analysis
 - Relative Permeability
 - Rock physics properties
 - Geochemical behavior

Geochemical Monitoring

- Fluid Sampling
 - Monthly Via U-tube in all monitoring wells until Breakthrough
- Tracers
 - Phase partitioning tracers
 - SF₆
 - ¹⁴CO₂
 - Rare earth element
- Core Testing & Analysis
 - CO₂ flood and flow experiments
 - Comparison of cores from gas cap with cores from injection zone pre- and post- injection

Geophysical Characterization & Monitoring

Well Logging

- All wells
 - Cement bond, Gamma / Density-Neutron, Resistivity, Sonic
- 1 Producer, Injector 4 Monitoring Wells
 - FMI, RST, MDT
- Annual Logging
 - Injector - MIT
 - Mon. Well – RST

Logs	Wells			
	All	1 st Prod	Inj	Mon
Cement Bond	Init			
Gamma / Neutron	Init			
Resistivity	Init			
Sonic	Init			
FMI		Init	Init	Init
MDT		Init	Init	Init
RST		Init	Init	Annual
MIT			Annual	

Vecta has unique technological skills ideally suited to the Kevin Dome area

- Specialty is multi-component seismic, a game changer for seeing stratigraphic traps and fractured reservoirs
 - shear-wave seismic data is a powerful tool for fracture detection and CO₂ monitoring in hard rocks
 - have been successful at imaging stratigraphically complex clastic and carbonate traps in environments similar to Kevin Dome
- Vecta is the only oil company that owns its own shear-wave sources and receivers, unique assets allowing us to cost-effectively acquire multi-component data



Vecta has unique seismic assets allowing cost-effectively acquisition of S data

Vecta Owns

**4 Shear Wave
Mertz 18 Vibrators;**

**900 Strings Oyo
multicomponent
geophones;**

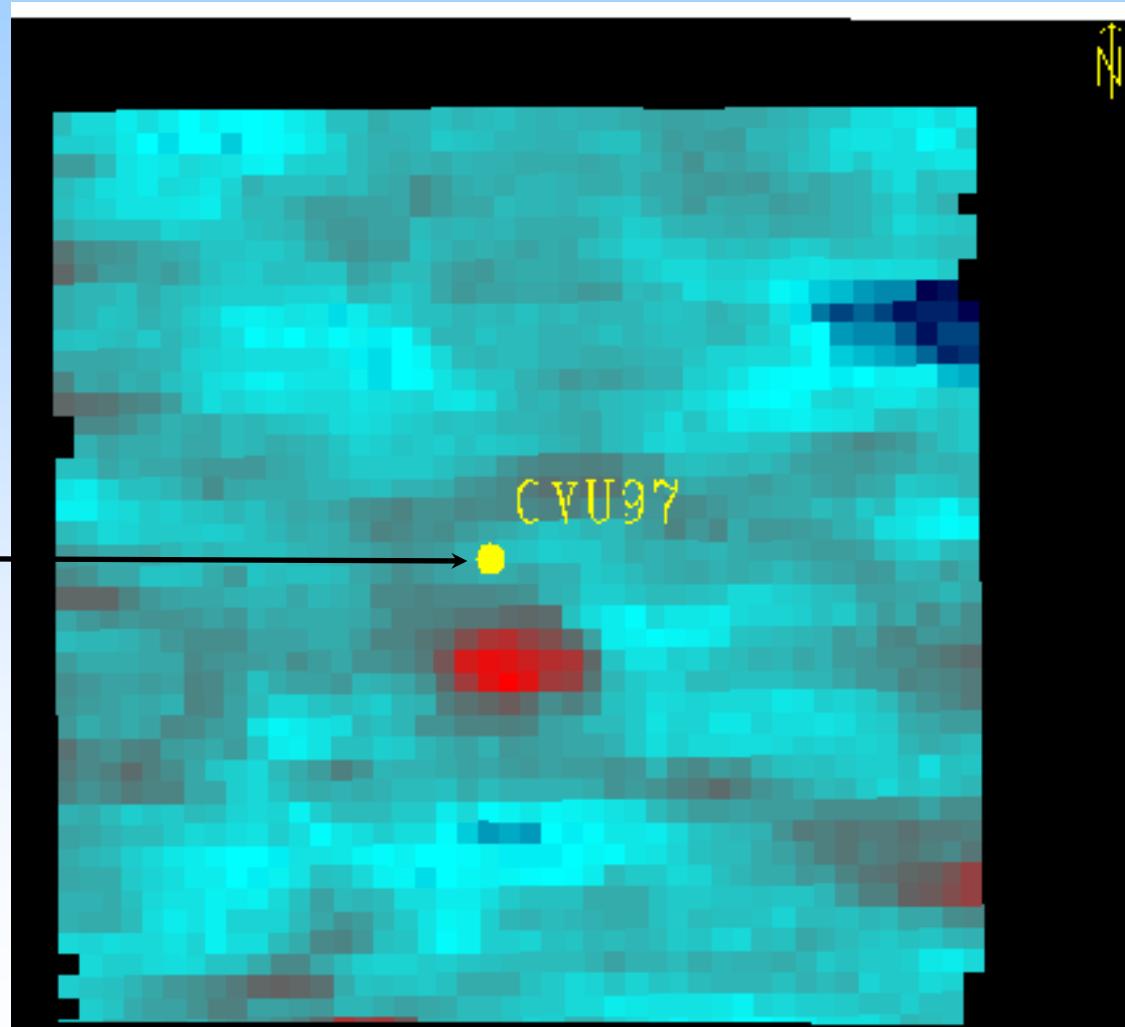
VSX MC Source



Time-lapse (4D) shear data is a proven tool for monitoring movement of CO₂ in fractured carbonate reservoirs

CO₂ injector

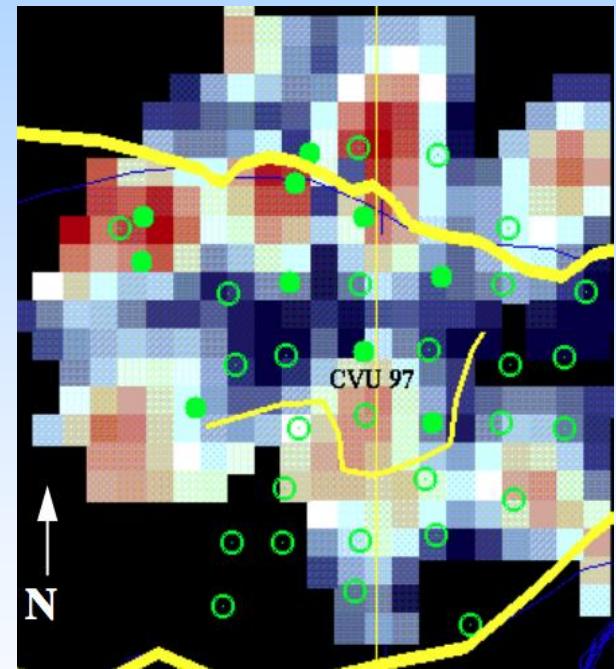
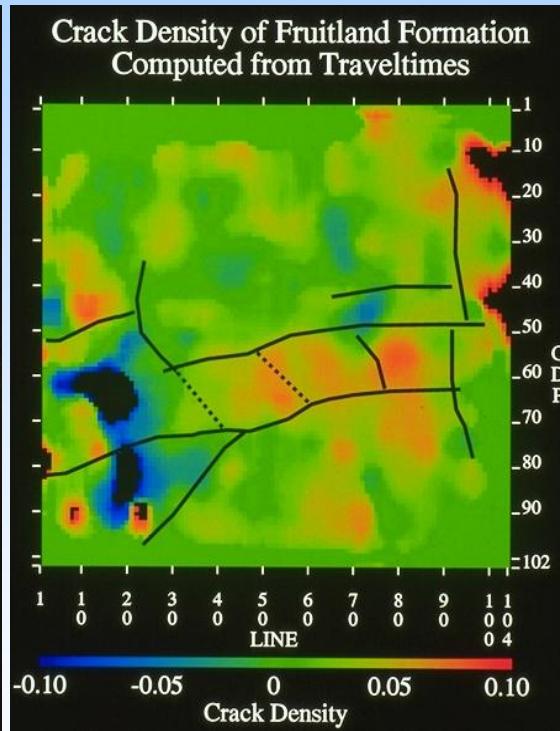
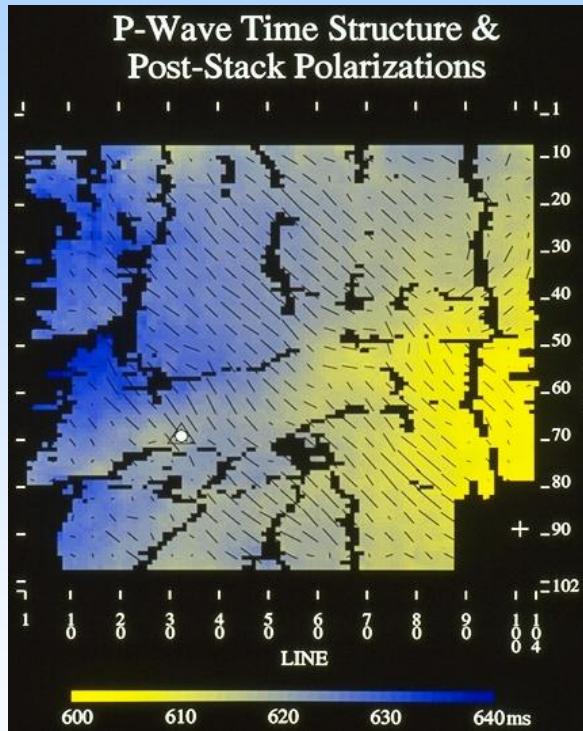
CVU97



Talley, 1997



Shear waves are much more sensitive to the presence of fracturing than conventional P-wave seismic data



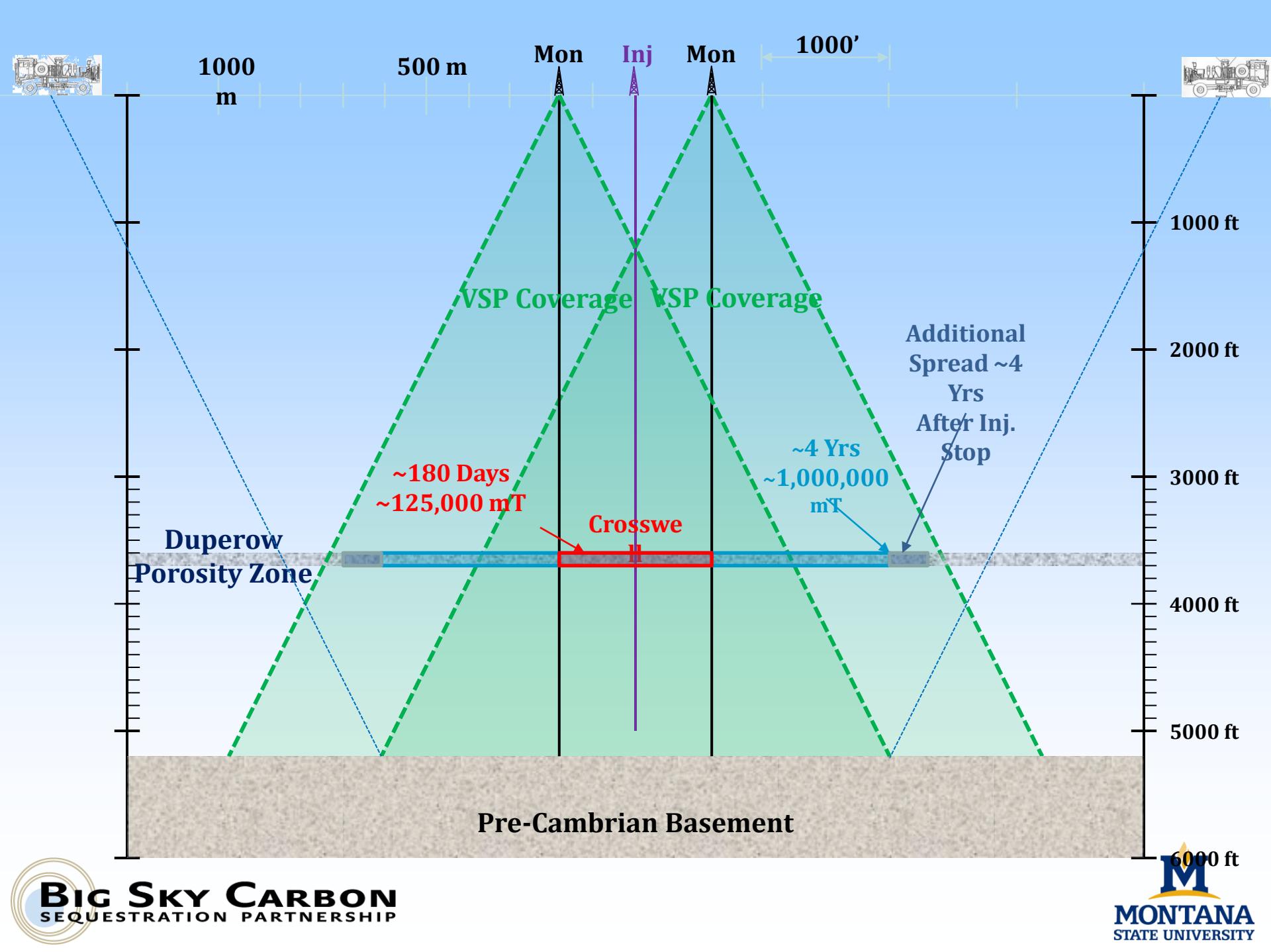
...and S1/S2 amplitude

differences give independent, high resolution estimates of fracture intensity

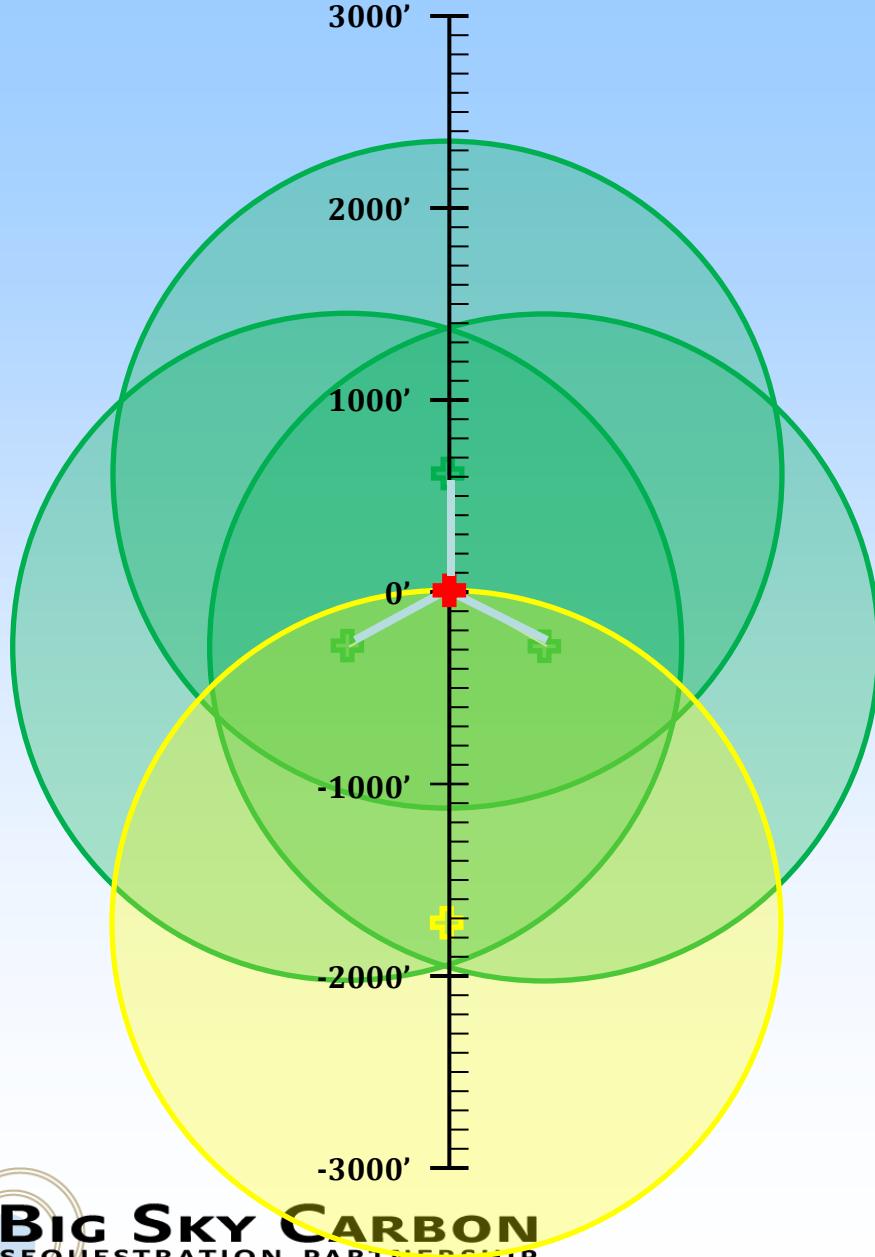
Geophysical Characterization & Monitoring

Seismic

	Cross Well	VSP (3D, 9C)	Surface Seismic (3D, 9C)
Seismic Survey Timing (Months)	0	0	0
	1	6	
	3		
	6		
		18	
		30	
		48	
			84

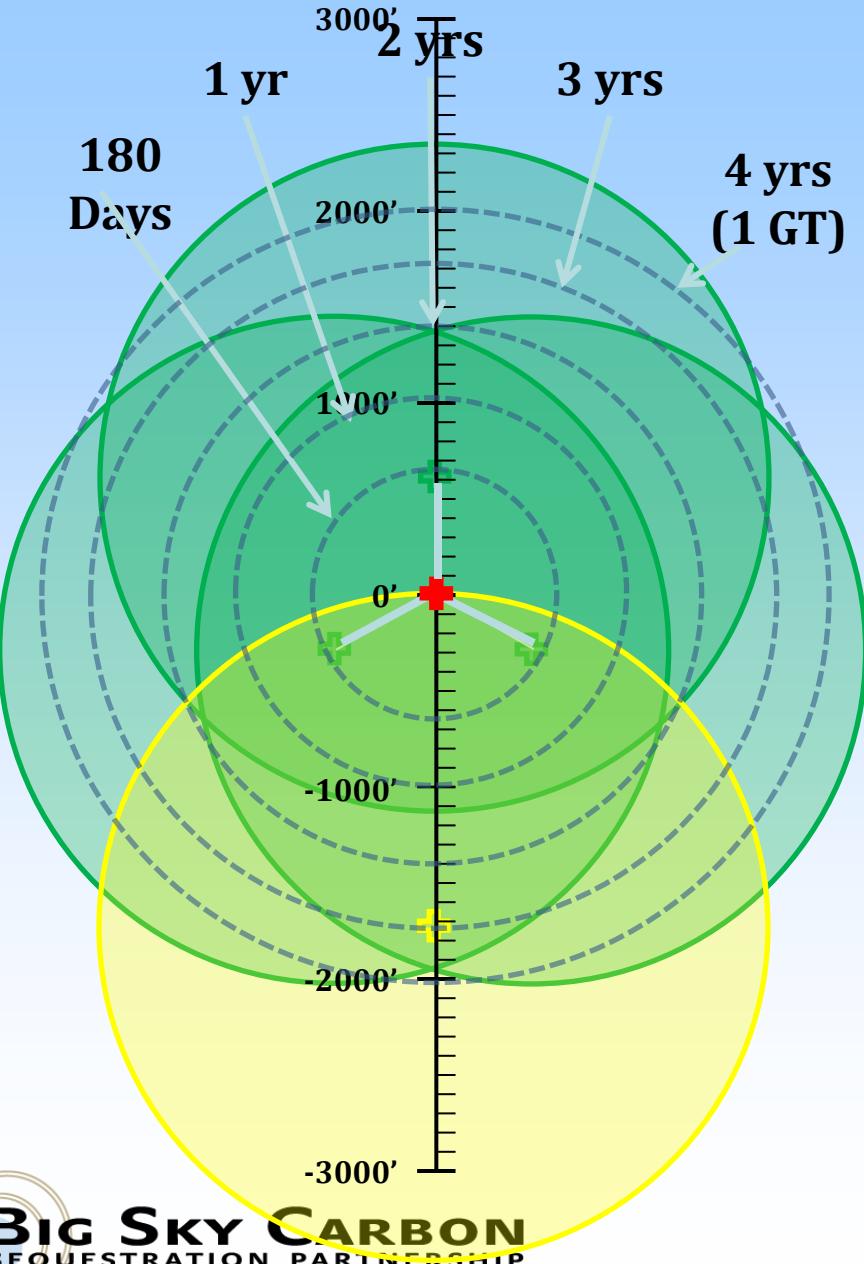


Monitoring Wells



- ✖ Injection Well & X-well Sources
- ✖ Geophone Wells
- Crosswell Lines
- VSP Areal Coverage at Duperow
- Calculated Plume Boundary

Monitoring Wells



Preliminary Simulation

Tough2, LBNL

12% porosity

50 mD permeability

700 tonnes / day

- ✖ Injection Well & X-well Sources
- ✖ Geophone Wells
- Crosswell Lines
- VSP Areal Coverage at Duperow
- Calculated Plume Boundary

Geophysical Characterization & Monitoring

Seismic

	Cross Well	VSP (3D, 9C)	Surface Seismic (3D, 9C)
Seismic Survey Timing (Months)	0	0	0
	1	6	
	3		
	6		
		18	
		30	
		48	
			84

Assurance Monitoring

- Eddy covariance
- Soil flux surveys
- Drinking water monitoring
- Hyperspectral imaging
- Differential Absorption Lidar

Acknowledgements

- DOE & NETL - Phase II Characterization Study
- Vecta Oil and Gas
- Bryan DeVault
- Dave Bowen

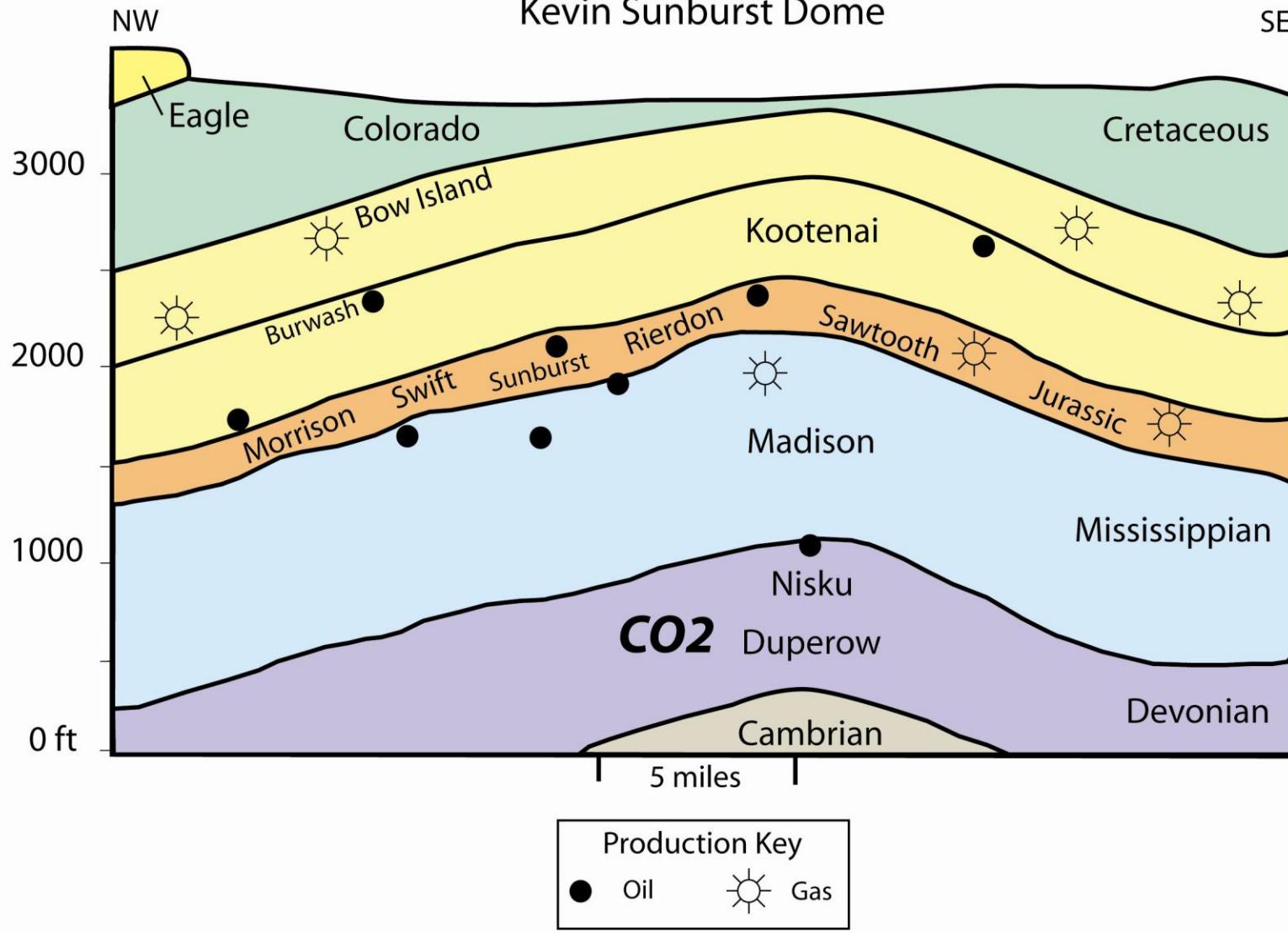




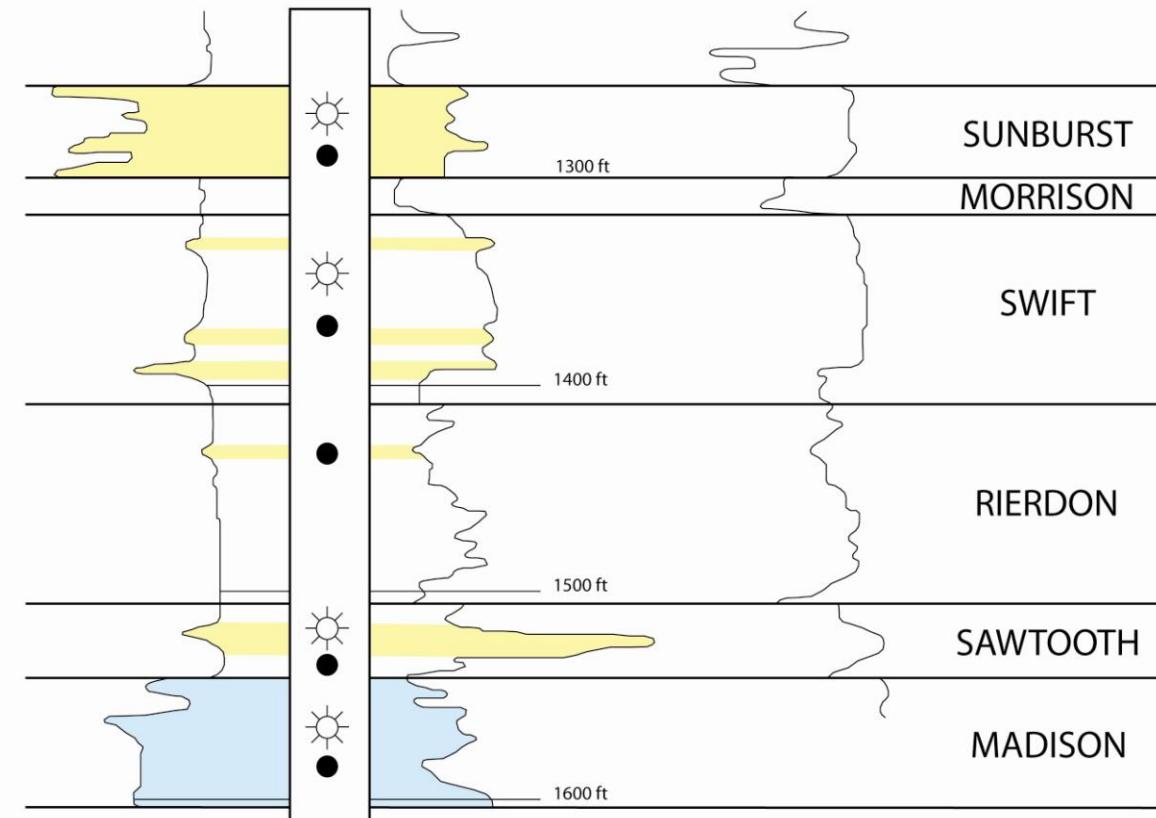
DOE Phase III Requirements

- Site characterization
 - Potential for commercial use
 - Deep saline reservoir strongly preferred
- Public outreach
- Baseline monitoring
- Injection of at least 1 MM Tonnes over 4 yrs
 - Second project may influence amounts
 - Anthropogenic source of CO₂ preferred
- Monitoring
- Reservoir flow modeling (predict CO₂ behavior)
- Post-injection monitoring 2-3 yrs
- Site abandonment, transfer

Diagrammatic Cross Section Kevin Sunburst Dome



TYPICAL LOG KEVIN-SUNBURST FIELD



Lithology Key

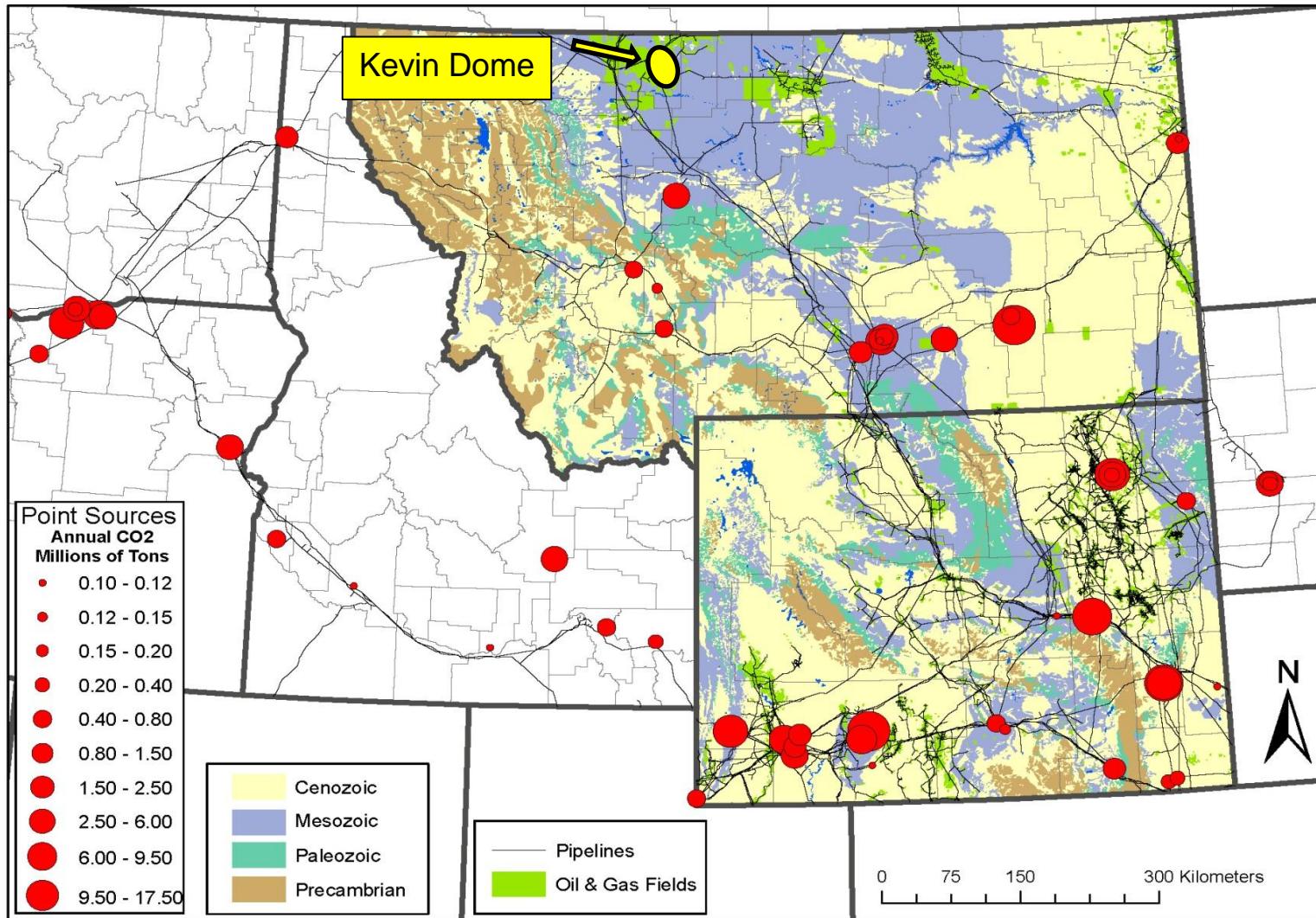
Sandstone

Limestone

Production Key

● Oil ☼ Gas

Location Map of Kevin Dome



Location Map of Kevin Dome Characterization Project



What are shear waves?

- vector v. scalar waves
- excited by horizontal vibrators shaking both inline and crossline
- 3-component geophones * 3 component sources = 9-C data matrix
- inherently “richer” dataset than P-waves, so common sense would suggest greater information content

